SCIENCE
TO-DAY AND TO-MORROW

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TO-DAY AND TO-MORROW

COMPILED FROM

A SERIES OF LECTURES

DELIVERED AT MORLEY COLLEGE

ILLUSTRATED

1932

WILLIAMS & NORGATE LTD

38 Great Ormond Street, London, W.C.1

PRINTED IN GREAT BRITAIN BY
UNWIN BROTHERS LIMITED, LONDON AND WOKING

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PREFACE

The essays collected in this book were based on lectures in a course on "Science To-day and To-morrow" delivered at Morley College for Working Men and Women, 61, Westminster Bridge Road, S.E. 1, in 1931.

The College owes a great debt of gratitude to the distinguished men and women, each of whom summarized so ably and lucidly the present position and the probable trend of the particular science in which he or she is expert. It is hoped that their publication in book form will bring to a larger audience the wide survey and keen interest which was in the first instance the privilege of the students of the College.

EVA M. HUBBACK
(Principal)

SCIENCE TO-DAY AND TO-MORROW

ASTRONOMY

by SIR FRANK DYSON, K.B.E.
The Astronomer Royal

In old times people looked at the stars and watched their movements and wondered, and not unnaturally thought they might have some influence on human affairs. I am afraid that nowadays, although people read about "The Mysterious Universe," they do not trouble to look at the stars. I admit there are difficulties, especially in London. But when opportunities come, in holidays or on a sea voyage, do not omit to use them by watching the stars and learning how our knowledge about them has grown up through the ages.

You will see first of all that the stars appear to be set in a great globe, which appears to rotate on an axle. Relatively to one another they seem to be fixed. The Great Bear, for instance, has a different position in the sky but the configuration of the constellation shows no change in the course of the night, or from night to night, or year to year, or to the naked eye for many generations. But some of the stars, and these among the brightest, appear to be crawling over the sky, and do not keep station with the rest.

The Moon is the quickest of these crawlers, and gets round the sky in a month. This was, of course, a very early astronomical discovery and the Moon has been used "for time and for seasons" from very remote antiquity. The movement of the Sun among the stars is more difficult to discern, although we all see that the Sun is high in the sky at noon in midsummer and low in midwinter. If there were no atmosphere we should see the stars in the day-time and the Sun's movement among them would be readily seen. However, astronomers found out thousands of years ago that the Sun moves round the sky in the same path year after year. This explains why the stars

change from month to month. In the winter we see Orion, but the sunlight hides him from view in the summer.

The other stars which appear to crawl across the sky are, of course, the planets. Mercury and Venus are seen after sunset or before sunrise, and appear to move from side to side of the Sun and never get more than a certain angular distance from him. Greek astronomers and mathematicians made order out of these puzzling movements. By a wonderful achievement of geometry they made a model of the planetary movements which served for 1,500 years. They were thus able to predict the positions of these planets for long periods ahead in fairly satisfactory agreement with observation.

Astronomy made little advance between Ptolemy's great book, the *Almagest*, in A.D. 140 and Copernicus (1473–1543), who put forward the proposition that the daily motion of the stars was explained by the Earth's rotation on its axis, and that the Seasons and the movements of all the planets were most simply explained by the annual revolution of the Earth round the Sun. Naturally, this made a great sensation. Common-sense said that such a movement could not take place without being felt. Cautious astronomers asked why no changes of relative position in the stars were detected when the point from which they were viewed changed so greatly in consequence of the Earth's motion. Conservative tradition clung to the teaching of Ptolemy and Aristotle. The Church denounced the doctrine as contrary to the Bible. Years later the great astronomer Tycho Brahe did not accept the Copernican hypothesis, though his observations were destined to give it the greatest support. He was a wonderful observer who constructed instruments of far higher accuracy than any earlier astronomers, and made long-continued series of observations. Tycho's observations of Mars were placed in the hands of his pupil Kepler, a skilful mathematician, and a most persistent and industrious man. He tried hypothesis after hypothesis. If one theory did not agree with the observations he turned the theory down and tried afresh. "God did not make such a good observer as Tycho and let him make observations so far from the truth." With infinite labour he discovered his famous laws of the

motion of each planet round the Sun in an ellipse with the Sun in one of the foci of the ellipse. This was an immense advance on the original Copernican system which retained a great deal of the complication of the Ptolemaic system. To learned mathematicians who could appreciate it, the simplicity of Kepler's planetary scheme, and its close accordance with the most accurate observations, was conclusive evidence of the heliocentric as against the geocentric system of the world.

Very soon afterwards other arguments were brought forward which appealed to the man in the street. These came with the invention of the telescope, a wonderful instrument which has increased our powers of vision to a greater and greater degree from the seventeenth to the twentieth century. Pointing a little telescope of his own construction to the sky Galileo found:

1. Many more stars than were seen with the naked eye.
2. Spots on the Sun.
3. Mountains on the Moon.
4. Venus showing a disc with phases like the Moon.
5. Four moons circling round Jupiter.

These new facts furnished a host of arguments in favour of the Copernican system. The spots showed that the Sun rotated on an axis. If the Sun, why not the Earth? Venus was seen to be a body like the Earth, illuminated by the Sun. Jupiter's moons revolved round him and were not left behind in spite of his motion. This removed the difficulty that the Earth's moon would be left behind as the Earth travelled round the Sun. The planets, instead of being mere points of light, were the Solar System as we know it to-day. Galileo had no difficulty in meeting scientific arguments, but the theologians insisted that the Scriptures, which they alone were entitled to interpret, overruled all arguments and observations.

Newton was born in the year in which Galileo died. By the law of Universal Gravitation he explained the movements of the planets, the tides, the figure of the Earth, the precession of the equinoxes, practically all the astronomy of his time.

As Mr. Bernard Shaw said, he made a Bradshaw for the planets. This had been an aim of all "astronomers" from the Greeks onwards. But the *Principia*, the book in which Newton developed his discoveries, is the greatest of all scientific works of genius and imagination.

The complete establishment of the Copernican system, from Copernicus to Newton, took two hundred years. It made a complete revolution in thought, besides being the greatest of all astronomical discoveries. This is my reason for having dealt with it in this lecture, before coming to the present-day astronomy of the Solar System.

Galileo found from the motion of sun spots across the disc that the Sun rotated in about twenty-seven days. Observations of the last and the present century have shown that all parts of the Sun are not rotating at the same rate. At the equator the period is twenty-five days, and increases as the poles of the Sun are approached. So that at 60° N. or S. of the Sun's equator the period is thirty days. As yet no satisfactory explanation has been given of this curious phenomenon. Sun spots have another feature as yet unexplained. Their frequency on the Sun has a fairly regular cycle of about eleven years. There were many spots in 1928 and it is safe to predict that there will be very few in 1935. These changes are in some way connected with the frequency of magnetic storms on the Earth and the appearances of Aurorae. Electrons and other small particles appear to be ejected from the neighbourhood of the sun spots. The subject is complicated and is engaging a good deal of attention at the present time. There are a great many things to be said about the Sun, but I must limit myself to the statement that it is composed of similar materials to the Earth, that it is a huge mass of gas with a temperature of 6,000° C. near its surface and a very low density. The temperature and density increase as we go inwards, so that at the centre the temperature is 40 million degrees and the density thirty times that of water. Some astronomers put the central temperature and density a great deal higher. The necessity for the high temperature is that the elastic pressure of the gas may balance the gravitational

attraction. The Sun is constantly radiating huge amounts of energy into space. In some way the energy is derived from sub-atomic processes in the Sun, itself. If the energy radiated were obtained from combustion of some such substance as coal, the Sun would be exhausted in a few thousand years. Helmholtz and Lord Kelvin estimated the total life of the Sun as 20 million years if its energy were obtained by gradual condensation from gravitational sources. This is entirely inadequate, for evidence is conclusive that the crust of the Earth indicates an existence of 1,500 million years. The positive and negative electricity of which matter is composed in some way coalesce in the interior of the Sun, and calculation shows that this would provide sufficient radiant energy to meet the Sun's output for many thousand millions of years.

We will leave this intricate subject and look at a picture of the Moon taken with the largest telescope in the world, the 100-inch reflector of the Mount Wilson Observatory.

The mountains and plains which Galileo saw with his little telescope are beautifully shown. The shadows of the mountains enable us to find their height, which is a little less than the highest mountains on the Earth. You will notice the crater-like appearances. How these were formed we really do not know. If I had been lecturing to you a month ago, I might have told you that the Moon was once part of the Earth, and told you something of the story of its birth. But quite recently a difficulty has been pointed out which makes astronomers doubt the view they have held for some forty years.

Venus is seen like a half-moon, as Galileo saw it. Mars is seen with distinct markings on it, some of which are permanent features. Possibly there is some form of life on Venus and Mars, but the evidence is very slight. On Jupiter you see the shadow of one of his moons. Saturn was a great puzzle to Galileo, and many years later Huygheus, with a better telescope, discovered the flat ring which varied its appearance when the Earth happened to be well above or below it, or when in line with it when the ring became invisible.

Saturn was the most distant planet known to astronomers till 1781. It is twelve times the distance of the Earth from the

Sun. As the optical power of telescopes has increased, many more members of the Solar System have been discovered. Most of these are small bodies from two to five times the Earth's distance from the Sun. Uranus, a large planet nineteen times as far from the Sun as the Earth is, was discovered by Herschel just 150 years ago. Neptune was discovered in 1846 as the result of mathematical calculations into the cause of small irregularities in the movement of Uranus. These were worked out independently by the French astronomer Levervier and the English astronomer Adams. The former has been honoured by a statue in front of the Paris observatory, and the latter by a tablet in Westminster Abbey with the inscription:

NEPTUNUM CALCULO MONSTRAVIT.

Only last year a still more distant member of the Solar System was discovered at the Flagstaff Observatory in Arizona. Percival Lowell, following the same line of thought as Levervier and Adams, tried to explain some still remaining irregularities in the motion of Uranus, as due to the attraction of a planet more distant than Neptune. He calculated that it was a planet some ten times as massive as the Earth, and started to search for it and left money for the search to be continued after his death. For a long time the search was unsuccessful, but in the end a planet less than the Earth, but comparable in size with the Earth, was found after very patient search by a young astronomer, Mr. Tombaugh, near the place indicated by Lowell. Astronomers are divided as to how far Lowell's prediction was a matter of luck, but all agree in their admiration of Mr. Tombaugh's pertinacity.

The table on page 15, in which the distances are in units of the Earth's distance from the Sun (93 million miles) and the diameter in terms of the Earth's (8,000 miles), gives some idea of the greatness of the Solar System.

In the eighteenth and nineteenth centuries many great mathematicians gave large parts of their lives to working out the details of the movements of the planets and their satellites. With the help of the astronomers, who gave the times when these bodies were in certain specified places, a most complete

	Satellites	Mass	Diameter	Distance	Time of Revolution in Years
Sun	—	330,000	109	—	—
Mercury	None	0·04	0·4	0·39	0·24
Venus	None	0·8	1·0	0·72	0·6
Earth	Moon	1·0	1·0	1·00	1·0
Mars	2 small	0·11	0·5	1·5	1·9
1,500 Asteroids	—	Small	Small	1·5 to 5·0	1·8 to 11·9
Jupiter	4 large 5 small	317	11·0	5·2	11·9
Saturn	8 large 1 small	95	9·0	9·5	30
Uranus	4 large	15	4·0	19·2	84
Neptune	1 small	17	3·9	30	165
Pluto	—	0·5?	0·8?	40	250

The masses, diameters, and distances are given in terms of those of the Earth, whose diameter is nearly 8,000 miles, mass 5,000 million billion tons, and distance from the Sun 93 million miles.

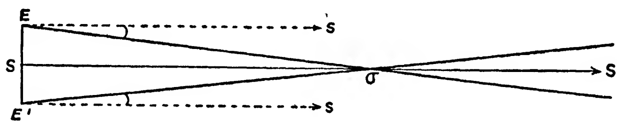
and exact "Bradshaw" has been worked out, and the positions can be predicted for hundreds of years. The great interest in this consists in the verification of the law of gravitation. As I said before, the divergence from the time-table led to the discovery of the planet Neptune. Does Newton's simple law explain everything? The most famous exception is a small unexplained movement in the planet Mercury, and this is explained by Einstein's theory. There is a divergence from time-table shown by early ellipses which indicate that the day is gradually becoming longer at the rate of $\frac{1}{1000}$ of a second every hundred years, and other slight divergences as yet unexplained.

We will now leave the planetary system and come to the stars themselves. They are all bodies like the Sun, shining by their own light. Some are much larger, others smaller than the Sun, and there are many millions of them. Before we can know much about them, we must find out their distances from us. This is a very difficult problem and astronomers only succeeded after great efforts and many failures, and after great improvements in their instruments. Let me take a much easier problem, the distance of the Moon, to illustrate how the measurement of the distance is made. Suppose the Greenwich and Cape Observatories agree to look at the Moon at the same time, and also a star which is near the Moon in direction. As the Moon is comparatively near the Earth, it will appear from the Cape to be more than 1° to the north of the star than as seen from Greenwich. As we know how far Greenwich is from the Cape it is is a simple matter to calculate the distance of the Moon from these observations.

A very similar surveyor's method is used by astronomers to determine the distance of the Sun. This is done in an indirect manner by measuring the distance of one of the planets. Kepler and Newton have shown how the relative distances of all the planets may be found. At any moment the Sun and planets can all be put on a plan, but the plan is like a map without a scale on it. The scale was determined first by the French astronomers who observed Mars simultaneously from Paris and Cayenne in South America. It has been determined many times since with increased accuracy. At the present

moment, if the night is fine, photographs are being taken of the small planet Eros at the Cape and Greenwich. Comparison of the position of Eros among the stars on these photographs will be used to determine afresh the Sun's distance. This is known at present to one part in 2,000, and we can only hope to improve the value 92,870,000 miles very slightly.

But it is no use trying to measure the distance of stars by comparing observations at Greenwich and the Cape. They are thousands of times too distant for any appreciable differences to be found in this way. As the Earth moves round the Sun at a distance of over 90 million miles, our point of view changes by 180 million miles every six months. In the diagram let S be the Sun, E and E′ the positions of the Earth, say on January 1st and July 1st, and let σ be a near star and s a distant one.



We will suppose for simplicity that the near distant star would be in the same direction as seen from the Sun. If s is very distant then it will be in the same direction seen from E and E′, and the sum of the two little angles indicated by the arcs is equal to E σ E′. When we know this angle accurately and the angles σ E E′ and σ E′ E approximately and also the base of the triangle E E′, then the distance E σ can be found. Actually the angle E σ E′ is always extremely small, less than 1″, or one part in 200,000. In practice more than one distant star is chosen, especially when photographic methods are used.

During the last century the distances of some eighty stars were measured, and very difficult and delicate work it was. In the last twenty-five years the distances of many stars have been determined by using large photographic telescopes. This is much easier but requires skilful work and a good deal of it.

Naturally the brightest stars were examined as being probably near, but actually some of them were found to be at very great

distances indeed. Another clue to the near stars is found by what is known as "proper-motion," i.e. the angular speed at which a star is moving relatively to its neighbours. Most of the stars hardly seem to move at all, but some move so quickly that their change of position can be observed in a year. For example, α Centauri moves $3''\cdot 8$ ($''$ denotes seconds of arc, not inches) in a year. This is so fast that it moves a distance in the sky equal to the apparent diameter of the Moon in less than 500 years. Thus it must be actually moving very fast or it must be near. So astronomers have used large proper motion as a second clue.

I give on page 19 a table of the nearest stars, and we shall see that it teaches a good deal.

The first column gives the name of the star, often called from the number of a catalogue in which it is found. Thus Gr. 34 means No. 34 in a catalogue of stars observed by Groombridge at Blackheath in 1810. The next column gives the magnitude of the star as seen in the sky. The fainter stars have the larger magnitudes. A star of 0·0 m. gives 100 times as much light as one of 5·0 m., and 10,000 times as much as one of 10·0 m. and so on. The third column gives the spectrum of the star, but I will only say that K and M stars are red, G stars yellow like the Sun, and A stars white like Sirius. The fourth column gives the "proper motion," and the fifth column the small angle called the parallax, which indicates the distance by its smallness. From these figures, the next three columns are easily calculated. They give the distance of the star, its actual motion in miles per second in a transverse direction (the motion to or from us is not given), and the brightness of the star as compared with the Sun, supposing it to be at the same distance.

We can learn a good many things from this table.

First of all, we notice how far apart the stars are. In a large sphere of radius 75 billions of miles there are only twenty-four stars. There may be some as yet undiscovered, but it is pretty certain that they will be faint, not one-hundredth part as luminous as the Sun. Now the diameter of the Sun is less than 900,000 miles. Roughly speaking the distances apart are 80 million

Name	Magnitude	Spectrum	Proper Motion Seconds of Arc	Parallax Seconds of Arc	Distance in Billions of Miles	Velocity across Sky in Miles per Second	Luminosity Sun = 1
Proxima	10·5	M	3·85	0·76	25	15	0·0001
α Centauri	0·3 1·7	G_0 K_5	3·68	0·76	25	15	1·1 0·2
Mun. 15,040	9·7	M_5	10·25	0·54	35	57	0·0005
Lal. 21,185	7·6	M_2	4·78	0·39	49	44	0·0054
Sirius	1·6 8·4	A_0 F	1·32	0·37	51	11	26·0 0·003
Anon.	12·0	—	2·69	0·34	56	24	0·0001
Cor. V. 243	9·2	M_0	8·76	0·32	59	86	0·0022
τ Ceti	3·6	K_0	1·92	0·32	59	18	0·35
Procyon	0·5 12·0	F_5	1·24	0·31	61	9	5·4 0·0001
ε Eridani	3·8	K_0	0·97	0·31	60	52	0·31
61 Cygni	5·6 6·3	K_7 K_8	5·20	0·30	63	73	0·06 0·03
Lac. 9,352	7·4	M_0	6·90	0·29	66	24	0·01
Σ 2,398	8·7 9·4	M_4 M_4	2·31	0·29	66	20	0·01 0·01
Gr. 34	8·1	M_2	2·89	0·28	68	30	0·007
ε Indi.	4·7	K_5	4·70	0·28	68	51	0·15
Kruger 60	9·6 11·4	M_3 M	0·87	0·26	73	10	0·002 0·0003
v. Maanen's star	12·3	F	3·01	0·25	75	37	0·0002
Cor. 29,191	6·6	M_0	3·53	0·25	75	43	0·04

times their diameters—though this is only an average, as some stars are much larger and some much smaller than the Sun. If we scale down so that 75 billion miles is made equal to the diameter of the Earth, we should have twenty-four bodies ranging from pin-heads to marbles and the largest no bigger than a football moving about inside it. Relatively to their sizes stars are very far apart, much more so than the molecules of a gas at atmospheric pressure.

A second point to notice is that no less than six of these stars are double stars, i.e. stars which move round one another under their mutual gravitation. Kruger 60, for example, consists of two stars whose masses are about 0·3 and 0·2 times that of the Sun, about 900 million miles apart and completing a revolution round one another in forty-four years. The two stars of α Centauri are each approximately as massive as the Sun, about 2,000 million miles from one another, and make a complete revolution in eighty years. Sirius consists of a large and bright star 2·5 times as massive as the Sun, and a small star of about the Sun's mass but of an extraordinary density, 50,000 times that of water. They take fifty years to complete a revolution. These figures illustrate the fact that the masses of stars do not differ very widely from one another. Examination of the last column shows how wide a range there is in the luminosities. Among these twenty-four stars the bright stars of Sirius and Procyon are more luminous than the Sun, but some of the stars are very faint, having a luminosity only a 10,000th part of the Sun. This may be taken as a fair sample of stellar population, though if we took a larger sample we should find greater extremes, coming occasionally across stars 100 or 1,000 times as luminous as the Sun.

As regards velocities, this is not a fair sample, as many of the stars have been picked out because of large proper motion. Velocities of fifteen to twenty miles a second are quite frequent, but velocities of more than fifty miles a second only occur in a small percentage of cases.

These direct determinations of stellar distances are important as they give a very complete knowledge about the stars which are nearest to us and are a guide as to what we may expect

at greater distances where we have to depend on average and statistical results. We can go about 1,000 million miles by this method, and that is a good start.

Herschel many years ago pointed out that there was in the movements of the stars a general tendency away from a point in the sky near the star Vega. He put forward the thesis that this was caused by a motion of the Sun carrying the Earth with it towards the star Vega. The stars have their own irregular movements, but such a movement of the Sun necessarily introduces a certain amount of system into the proper motions as viewed from the Earth. Suppose people are walking in all directions over a field. To an observer standing still there will be as many moving in one direction as another. But if this observer walks in a northerly direction, the other folks will appear to him to have a general drift in a southerly direction. This in three dimensions is what we see in the sky—the apparent movement towards a point being a perspective effect. This method has been applied very extensively and gives average relative distances of stars of different magnitudes or of different colours.

In the present century a more complete knowledge of stellar movements has been obtained by the determination in miles per second of the rate at which stars are approaching or receding from the Earth. Many years ago the suggestion was made by Huggins that this might be achieved by fixing a spectroscope to a telescope. The light from a star is passed through a prism and is seen as a coloured band. In this band there are certain dark lines caused by the presence of chemical elements such as hydrogen or iron in the atmosphere of the star. When a spectrum of iron, obtained by means of an electric arc with iron in the poles, is placed for comparison beside that of the star, the lines due to iron are seen in nearly identical positions, but they may be all shifted a very minute amount towards the red or the blue end. Now just as the note of the whistle of an approaching locomotive is raised, because more vibrations reach the ear than when the locomotive is at rest, so more vibrations of light from the particular iron line under consideration are received if a star is moving towards us, and the

line is seen to be shifted slightly to the violet. Although Huggins and others tried hard they did not get satisfactory results, and it was not till photographic methods were introduced by Vogel that much confidence could be placed in the results. The large telescope of the Lick Observatory was applied by Campbell extensively to this kind of work and later the telescopes of Mount Wilson and Victoria especially have been similarly used. The quantities to be measured are small, and great care and skill as well as large telescopes and good photographic plates are needed. The velocities of many thousands of stars have been determined, and as with the angular motions across the sky, there are great irregularities, but there is a general drift away from a point in the sky near the star Vega. From the average of many stars the velocity of the Solar System through space is found to be about twelve miles a second. Now twelve miles a second is just over a million miles a day, and so in a year the Solar System has moved about four times the Earth's distance from the Sun, and in a century about 400 times this distance. Now the proper motions of many stars have been observed for well over a century, but we cannot tell in any individual case how far the change in a star's position in the sky is due to our change of point of view, and how far it is caused by the motion of the star itself. But we can obtain important average and statistical results, and get a fairly good idea of how far the apparent brightness of a star is due to its distance and how far it is due to the intrinsic luminosity of the star itself. As an instance of the results obtained from these statistical researches we find the relative numbers of stars of different luminosity.

These are:

24	100 times as luminous as the Sun.
340	50 ,, ,, ,, ,, ,,
1,530	25 ,, ,, ,, ,, ,,
4,840	10 ,, ,, ,, ,, ,,
23,000	as bright as the Sun.
94,000	one-tenth as bright as the Sun.

These methods have enabled us to penetrate into space ten times as far as we can go by our surveyor's methods of

measuring distances, i.e. to seven or eight thousand million million miles—or in the astronomical units, 400 parsecs—a parsec being 19 million million miles, and corresponding to a distance at which the line joining the Earth to the Sun subtends one second of arc. As the distances in miles are growing larger I shall talk of parsecs for the future. Well, 400 parsecs is about as far as we can get by observing changes in position of the stars. By optical methods we can go a great deal further, and I must now explain these, as I don't like to tell you of wonderful results without saying how they are found.

Quite lately these big stellar distances have been got in a new and a very interesting way, which it is very easy to understand. There are certain stars in the sky which are variable stars. The variability is sometimes caused by a dark star going round a dark one; but that is not the cause of the variability of these particular stars. These stars are called Cepheid variables, and they can be recognized very readily by the way they go up and down in brightness. We can thus detect a star of this kind, whether it is a faint star or a bright star. These changes may occur in three, four, five, or ten days, but they are repeated with regularity, and a star may oscillate in this regular way between the fifth and fourth magnitude or between the fifteenth and the fourteenth magnitude; still it changes the same amount in magnitude (i.e. the same fraction of its light) in the four or five days.

A lady, Miss Leavitt, at the Harvard College Observatory, detected—it was a very clever thing to do—in the Magellanic cloud (a remarkable cluster in the Southern Hemisphere) quite a number of these Cepheid variable stars. She took a number of photographs, and she found variable stars fifteenth, sixteenth, and seventeenth magnitude, and she saw that some of them varied from fifteenth to sixteenth magnitude, some from sixteenth to seventeenth, and so on. That was not an easy thing to find, but by taking photographs day after day she saw that one particular star was a little bit fainter, another a little bit brighter, and so on.

She found that those stars, which took five days to go through their period, were brighter than those which took only three or

four days; and gradually she found that there was a distinct relationship between the period of the oscillation and the brightness of the star. For instance, stars of 16½ magnitude took three days to go up and down; stars of 15½ magnitude took ten days, stars of 14½ magnitude took thirty days, and so on.

Then a Dutch astronomer said: "These stars being all in the Magellanic cloud are at practically the same distance, so there must be a relationship between the actual brightness of the stars and the length of time they take in their oscillation of brightness; it is a thing intrinsic in the stars themselves and has nothing to do with the Magellanic cloud."

So by looking up at the Cepheid variables nearest to us—and there are a number, of which the Pole star is one—and using the methods I talked about a little time ago to find the distances, he was able to get an exact formula, giving him the actual brightness of these stars as compared with the Sun.

For instance, he found that a star which goes through its period in three days is 250 times as luminous as the Sun, and one which takes five days is 330 times as bright as the Sun, and so on. Now the Sun at a distance of ten parsecs would be seen as a star of the 5th magnitude. At ten times this distance, i.e. at a distance of 100 parsecs, the Sun would appear to us 100 times as faint or of 10·0 m. But a star 330 times as luminous as the Sun would at this distance appear to be of magnitude 3·7 m. Thus a Cepheid variable with period of five days is 3·7 m. at 100 parsecs distance; it will be 8·7 m. at 1,000 parsecs; 13·7 m. at 10,000 parsecs; and 18·7 m. at 100,000 parsecs. In this way the Magellanic cloud of stars was found to be at a distance of 32,000 parsecs.

This was the beginning of what proved to be fairly accurate measurements of big stellar distances. There are in the sky a number of clusters. There is a very fine one in the constellation Hercules. There is another cluster in the Centaur, a constellation seen in the Southern sky. In these clusters there are a number of Cepheid variable stars which have been used to determine the distances, and these distances are pretty big. There are not many of these clusters, about 100, some of them large and some small. They are nearly all in one

hemisphere of the sky, and, roughly speaking, are not far from the plane of the Milky Way. The distances of these are anything between 10,000 and 40,000 parsecs.

An American astronomer, Mr. Shapley, the astronomer at Harvard College, said to himself: "This is a very curious thing; these clusters are clearly related to the Milky Way and it seems to indicate that the centre of the Milky Way is to be found at the centre of these clusters." I hope you know the appearance of the Milky Way. In these latitudes we see it well in the constellations of Cassiopeia and Cygnus. It stretches like a band all across the sky but its brightest part is too far south for us to see it well. Many years ago, Herschel made extensive counts of the faint stars he could see in different parts of the sky with his large telescope and concluded that the system of the stars was flat like a watch and extended ten times as far in the plane of the Milky Way as in the direction perpendicular to it.

The constellation of Ophiuchus is the part of the sky where Mr. Shapley found the centre of the hundred clusters. He drew the conclusion that the centre of the Milky Way was in this direction and at a distance of say 15,000 parsecs. Previously, only twenty years ago, an astronomer had come to the conclusion—and other astronomers had also—that we are fairly near the centre of the Milky Way; he made very laborious statistical calculations from the class of stars, the proper motion of stars, the velocity of stars, and so on, but these statistical methods are always difficult, and direct observations are generally more satisfactory, although they do not always agree with what you had before—and that is what occurred in this case.

Soon after Mr. Shapley's result, a Dutch astronomer, Mr. Oort, from general observations of the velocities of stars, determined by the spectroscope, proper motion, and so on, working on the hypothesis that stars, including our Sun, were revolving about the centre of the Milky Way—which we would naturally expect, otherwise they would fall in. He set to work to find out from these observations where the centre was, and he found that this second line of work gave nearly

the same position as that found by Mr. Shapley from the clusters. This was confirmed further by Mr. Plaskett, a Canadian astronomer, who made special observations with the large telescope at Victoria. All the stars, including the Sun, are revolving round this centre. The Sun and the stars within 1,000 parsecs of it take about 200 to 250 million years to make a complete revolution. Well, 250 million years is not particularly long to an astronomer; geologists tell us that the age of the rocks on the Earth is something like 1,500 million years. So in that period the Sun will have gone six times round the whole system of the Galaxy. The whole distance to the centre we do not know so well, but it is something like the order of 10,000 or 15,000 parsecs; we do not know the total number of stars, but we know that total mass is something like 100,000 million suns.

But that is not the whole story. Now I want to say a word or two about the nebulae. The great nebula seen in the sword of Orion is not very far away: about 100 or 150 parsecs, in fact quite near. It is a great mass of gas more or less transparent.

But some nebulae, like that in Andromeda, are entirely different. Examination of its spectrum shows that it is constituted like the Sun and stars, and for many years astronomers have believed it to be a very distant collection of stars, which our telescopes were not sufficiently powerful enough to see as separate stars. Quite recently with the big telescope at Mount Wilson the nebula has been partly resolved into separate stars. By means of hundreds of photographs, Mr. Hubble has detected a number of these Cepheid variable stars. They are extremely faint at the brightest, but the regular variation of their brightness has been clearly established. He has then used them as standard lamps of say 330 Sun power; and has calculated the distance of the Andromeda Nebula as 300,000 parsecs. It takes the light nearly a million years to reach us from this great distance. There are many millions of stars in this nebula, which is an "Island Universe" situated far away from the Milky Way system to which we belong.

There are a great many of these nebulae and we are certain that they are all collections of stars. We can determine the

distances of the nearer ones from the Cepheid stars in them. For the more distant and smaller ones we have to depend on their sizes for a rough idea of their distance. There are a good many hundred thousand of these nebulae in the sky. The most extraordinary thing about them is this: when their velocities are measured by the spectroscopic method—mind you it is difficult, because of the faintness of the bodies—we find that they are all moving away from us; and, a most extraordinary thing, the farther off they are the faster they are moving away; and it is a good pace, reaching hundreds and even thousands of miles a second. This is in agreement with Einstein's theory that gravitation is due to the curvature of space and that the Universe is finite but unbounded. It is no good trying to imagine this, but we have as an analogy that the surface of the Earth appears to be flat when we consider small distances but we know to be spherical. Quite recently the Abbé Le Maitre, Professor of Louvain University, has shown that these movements indicate an expansion of the whole Universe like an indiarubber balloon which is being inflated. I cannot attempt to explain this; but there is no question about the fact that these nebulae are big collections of stars, which appear to be moving away from us with very great velocities, and the farther they are off the quicker they are moving. So I will conclude by quoting a saying of Lord Rayleigh quoted in his *Life* written by his son, "The most wonderful thing of all is that you and I are here to talk about it."

[Many slides were shown by the lecturer. They are not reproduced, but the reader is recommended to visit the Science Museum and look at the collection of photographs and models there.]

PSYCHOLOGY

by EMANUEL MILLER, M.A., M.R.C.S., L.R.C.P., D.P.M.(Cantab.)

A CRITICAL shaft that has been frequently directed against psychology in the last thirty years has been that psychology lacks scientific cohesion, that it does not know what it examines, nor how to examine it, that, unlike the fixed sciences, it is devoid of units upon which the prediction and ordering of phenomena can be based. Its inner dissensions give it the appearance of a battlefield of religious differences rather than the calm discussion of scientific workers. It is further urged that, even on the purely qualitative side, its power of describing human behaviour, motives, and passions, falls far short of that displayed by poets, novelists, and moralists; that the way in which its concepts are used are the despair of the logician and the joke of philosophers. The splendid spectacle of the progress of the fixed sciences in other fields was held up as an example.

To pass, for example, from modern astronomy to modern psychology is to pass from the nebular to the nebulous. These taunts are at once true and false. In the first place, they fail to take into account the nature of the material of psychology as well as of its problems. In particular, they fail to realize the obstinate human fact that the very nature of psychology places it at the very heart of human problems, and what is near the heart must necessarily provoke the passions of vested interest and the resistance of obstinately rooted beliefs and prejudices. To discuss human problems at all is to arouse differences of cultural outlook, themselves embedded in generations of religious and social subsoil. People dread lest the uprooting or exposure of the roots of their beliefs and opinions should lead to the withering of all that they hold dear in the intellectual and the moral field. The fixed sciences, so called, do not necessarily arouse deep feelings either of devotion or of antagonism, and when they do, it is again because human prestige is attacked or some aspect of human pride, embodied in institution, is scandalized.

Evolution, arising from the innocuous fields of botany and zoology, seems to mock at the alleged divinity of man, and even the investigations of astronomers dealing with the remote in time and space had its martyrs in Galileo and in Tycho Brahe. Only to-day astronomy has so etherealized our universe that it is at one and the same time a thought in the mind of deity yet a reality to man, an aesthetical gesture of a divine artist and yet the basis of a coherent system of knowledge making astronomy possible. We do not quarrel about the destiny of comets or the state of nebulae, but we are not prepared to sit satisfied while our emotions are measured and our sensibilities are reduced to logarithmic formulae. The advantage that the fixed sciences have over psychology or over any of the human or normative sciences is that they appear to pursue their uninterrupted courses devoid of subjective references and entirely bent upon the examination of the relationship between facts in the external world.

Psychology, however, has been steadily approaching the methods of objective science, partly because its students have attempted to follow the objective approach of other sciences, and partly because its subject-matter has made liaison with the fixed sciences of physiology, chemistry, and physics. But however the psychologists (at least those that have emancipated themselves from philosophy) have increasingly studied human beings objectively in their behaviour, they are still, in the ultimate reduction, tied to subjectivism; that is, the conscious self, or the individual who is aware. The self or subject remains a nucleus or irreducible centre of reference to which, and from which, all study of behaviour finally returns.

Time was when philosophy in the hands of the philosopher-mathematician Descarte split the human being into a body and a mind, and all the theories of body and mind since that time have attempted to bridge the gulf or to find drastic means of overcoming this bifurcation by denying either mind on the one hand or matter on the other. This problem remains in the background of every department of psychology, and however we may try to avoid the issues by setting up purely mental or

purely physical standards for the construction of theories of human behaviour, the clear understanding of the main currents of modern psychology can only be achieved if we have reasonably clearly in mind this fundamental problem. If one were to bring into relief the three main currents of modern psychology, one would define them as:

1. The struggle of physiology with psychology; that is to say, the effort to establish human behaviour on a mechanistic basis.
2. The development of the study of Intelligence, its numerical assessment, and the effect of this study on education and mental deficiency.
3. The development of dynamic psychology as embodied particularly in the study of our instincts and emotions, and above all, of the Unconscious Mind and its influence in health and in disease.

Each of these currents may be said to pursue its course independently; but such departmentalism is purely a matter of economy and of methodology, for in psychology there is an intimate relation between all these currents, and for the non-specialist in particular it is essential to see these currents as processes in one united system. If we are to study man completely, the study of man in aspects must never lose sight of the integration of the whole.

The powerful movement towards a mechanical explanation of human behaviour is due to the truly remarkable advances in human physiology; and in particular to the growth of our knowledge of the structure and function of the nervous system. The light that chemistry and physics have shed upon the action of our organs of digestion, upon nutrition, and upon the function of the blood and the internal secretions is all in favour of purely physical methods. Day after day the field of chemistry relentlessly invades the old physiology, pushing back into a smaller and smaller field the vitalistic explanation of bodily activity. These victories are so remarkable that no one pauses to question the fundamental tenets upon which the physiology of life is based, but rests satisfied with the practical successes

of the mechanistic methods. Substances that were once regarded as essentially vital in structure and beyond human imitation are being manufactured in the laboratory, and processes which at one time seemed to need the operation of a vital principle are now satisfactorily explained in terms of physical chemistry.

Physiologists, physicians, and psychologists are daily witness to the effects of the secretion of certain glands not alone upon growth and general physical well-being but upon intellectual development, upon temperament, and upon such complicated functions as sex itself. Feeding with thyroid, for example, will lead to the recovery of a dull, apathetic, and physically desiccated woman. It will turn a stupid and repulsively stunted child into a creature reasonably intelligent and good to look upon. Removal of a tumour upon the suprarenal gland in a girl who was fast losing her normal sexual characteristics and assuming male characters of mind and body restored her to normality in both respects. Little wonder, therefore, that the over-enthusiastic re-write the psychology of temperament in terms of the activities of the internal secretions.

As far as the nervous system is concerned, we have gone beyond the elementary stage of neurology which regarded the brain and the spinal cord as merely serving the interests of the senses and the movements of the body. We have, in addition, passed beyond the crude phrenology which supposed that the isolated and ideally separate faculties of the mind were instrumented by localities in the brain. Disease, experiments upon animals, and the valuable experiences of the Great War have taught us that the organs of sense are themselves delicately co-ordinated and that the beautiful co-ordination of our movements and postures is due to the integrative action of the nervous system rather than to the isolated activity of different portions of the cerebro-spinal system.

Speech, the instrument of man's social contacts, the embodiment of a large part of his culture, is dependent upon health and integrity of the brain working as a whole. Study of comparatively minute aberrations of speech function are closely

associated with the senses of hearing and of sight and of the motor functions of the hands working in proper harmony with them like a well-rehearsed orchestra. Sir Henry Head has shown from his observations upon gunshot wounds in the head that the grammatical structure of language as well as our apprecia-tion of the bare spoken and seen word is dependent upon a widely organized speech mechanism. Learning, too, upon which our delicate control of environment depends, is associated with the function of the highest levels of the brain. Professor Pavlov, the celebrated Russian physiologist, has shown by exquisitely arranged experiments that dogs can be "conditioned" to perform acts which are ultimately based upon the simple reflex mechanisms of the nervous system. He has demonstrated that if the action of secreting saliva at the sight of food—a reflex act—is repeatedly associated with another stimulus such as a pinch, an electric shock, or well-defined musical note, then the mere appearance of the latter stimulus, whichever it may be, will result in the production of saliva in the absence of the sight of food. He also found that sleep, too, can be induced under certain experimental conditions even in the absence of what is normally regarded as fatigue. Pavlov argues that these experi-ments are proof that the ultimate units of animal behaviour are the reflex acts, and that our most complicated activities which have hitherto been expressed in psychological terms alone are but complexes or patterns, neural patterns, based upon such ultimately simple conditioned reflex themes. Watson in America, and the co-workers of Pavlov, have extended the work to the field of the study of the human child. Here too the conditioned reflex has had its victories, and in the laboratory the child has been made to eat, as it were, out of the physi-ologist's hand by the mere conditioning of simple reflex acts.

Combine for a moment the spectacular results of the study of the internal secretions with the equally startling results of Pavlov's work, and we seem to have capitulated to physiology. Let us for a moment examine the validity of Pavlov's argument as to the nature of human behaviour and animal behaviour from his experiments. If a Martian visitor to this planet were confronted with the latest calculating machine, or with a

complex printing machine, he would be able to describe their mechanism and the integration of their parts. He would further, if he saw them in action (let us subtract for a moment the human operator), be able to deduce their function, but would he be able to prophesy the specific calculation touched off in the calculating machine or the opinions expressed through the medium of a printing plant? The very fact of a Martian applying himself to the machine assumes in him a mechanism comparable to the machine he contemplates. It would follow that he possesses functions or directions—let us not for a moment use the psychological term "aims"—that are capable of expression through such machines. Above all, it assumes a knowledge of the historical background of such devices, that is, how they came into being, and what aim there was in their construction, and what processes were manifest through them. How can a human-made machine be understood in the absence of a knowledge of its history? Such history does not reside in the machine itself but in the agency that has set it going and in the processes that take place through it. So, too, the simplest animal act depends upon retentiveness, or the power of retentiveness of the nervous tissues. What is it that activates this retentiveness? Whether animals possess rudimentary images is a debatable subject, but as human beings we are aware of images or traces of past events that have happened to us or which we have suffered. These are the springs of action. It may be that the image is just the aura or phosphorescence which accompanies an act which is on the point of taking place, this latter being, perhaps, a purely physiological process, but the awareness of the image accompanying the act seems to be simple and indefinable. Learning an action in the absence of such images or back references is difficult to contemplate. To suggest, as the mechanists do, bare traces of past events, and that these are actuated or "tickled up," as it were, by an associated stimulus, and that these produce speech activities of a low grade, and that these produce the so-called image—verbalizations as they are called—seems to be merely playing with words. When the mechanistic theory gives us a reasonable explanation of the phenomena of images and finally of memory, as ex-

periencing beings perceive them in reverie and even in action, then psychology can honourably surrender the field to physiology. Till then the mechanistic approach remains pre-eminently a valuable laboratory technique for the investigation of animal and human behaviour regarded as observable phenomena rather than as experienced phenomena. Even if the data of feeling and emotion are ultimately explained in terms of bodily events, that is, physiological changes, the fact remains that feelings, whatever they may be, are experienced; they are felt.

Recent investigations in Germany by the so-called Gestalt school of psychology afford strong arguments against the atomic growth of the mind which mechanism alleges to demonstrate on the basis of reflex acts. By experiments, particularly concerning our perception of the external world through the visual channel, the leaders of the Gestalt school of psychology have been led to the belief that they have demonstrated that mental growth takes place along lines of massive organization and not by the addition of unit increments of stimuli one with another, producing discrete sensations which grow together. In perceiving the blue sky we do not come to this appreciation by the addition of a series of blue sensations one to another but by the perception of a blue whole, a perceptual structure which is of the nature of a continuum in which the parts are entirely dependent upon the whole. Koffka says, for example, "Our space perception is the result of organized brain activity, and we can understand our space perception only in terms of organization, that is, in terms of actual, dynamic processes, and not in terms of mere geometric stimulus—sensation correlations. . . . If we treat perception as the result of ever-changing stresses producing new and ever new organizations, we shall find in our subject something of the drama of life, the interest in which has attracted us to psychology." In fact, the organism with its organization for living as a whole seems to reach out to the environment rather than merely to suffer the successive stimuli which are supposed to reach it in a series of units. What is true at the level of perception must prove to be true of higher activities of integration also, whether

we describe them in terms of the nervous system or whether we describe them in terms of an experiencing agent of the mind. The work of Professor Lashley in America on the learning processes of animals who have been experimentally injured bears this out, that is, that despite profound local injuries to the brain, sometimes very extensive, a total organization seems to be concerned in the learning process which embraces more than unit areas of the brain. He says, speaking of Head's work on Aphasia: "The defects can in every case be related to ways of thinking about things but not to loss of specific associations. . . . I believe that there is ample evidence to show that the units of cerebral function are not single reactions, or conditioned reflexes, but are modes of organization. The cortex seems to provide a sort of generalized framework to which single reactions conform spontaneously as the words fall into the grammatical form of a language. . . . The activity of the nervous system suggests that it is capable of a self-regulation which gives a coherent logical character to its function no matter how its anatomical constituents may be disturbed. If we could slice off the cerebral cortex, turn it about, and replace it hind side before, getting a random connection of the severed fibres, what would be the consequences for behaviour? From current theories we could predict only chaos; from the point of view which I am suggesting we might expect to find very little disturbance of behaviour. Our subject might have to be re-educated, perhaps not even this, for we do not know the *locus* or character of habit organization—but in the course of his re-education he might well show a normal capacity for apprehending relations and for a rational manipulation of his world of experience."

According to Sanders the structural totality is the personality as the total of all substructures. He says: "All subordinate structures are organically incorporated into the total structure of the personality; from them, as members relative to the whole, shines forth the lawfulness of the whole. . . . The specific directions of the separate substructures almost never shine together in their organic unity though they are always borne within a whole, but usually a highly strung whole in which

now the one, now the other, determines the actual process of experience, attitude, and action, though always in conformity in the immanent plan of the whole." In considering later the data of psycho-pathology we will have occasion to see how deep the mental unity can go, and to what extent it is subject to substructures, the instinctual processes, and their organization into complexes and sentiments respectively below and on the level of conscious awareness.

The Problem of Intelligence

Unlike the advances in the fixed sciences, the progress of those sciences which are intimately related to human affairs receives its impulse not infrequently from social necessities. In psychology this has been shown very clearly in the development of the scientific assessment of degrees of intelligence. Some forty years ago in France it became increasingly necessary to establish a scientific method of putting into numerical form for the purposes of education administration the degree of intellectual development in school children. There was a growing necessity, not only for the grading of normal children on the educational ladder, but for the relating of backward and deficient children to the normal school curriculum. Before this period the estimate of teachers and of educationalists was based upon no standardized test and no criterion of normality was used. The estimates of teachers were then, as they largely are now, qualitative and governed by particular interests. Nor were teachers aware of the disturbing factors in child life which made for apparent backwardness, nor of the way in which quite deficient children displayed a charm and busyness which gave the impression of intellectual normality. Binet, the pioneer of mental testing, set to work to devise tests which would help to classify children in such a way as would create standards of intelligence for general application in terms of mental age. Starting with a large number of tests he applied them to normal children of all ages and by so doing he came to the conclusion that for each chronological natural age there were tests that the average child ought to perform satisfactorily. From this there

grew up a scale of tests ranging from the age of three to the sixteenth year. These tests—about a half a dozen for each year—were designed to exercise each of the outstanding mental operations which were developed up to a given age in ascending order of difficulty. Thus, a child of three was expected to point accurately to parts of its body that were named, to perform simple tasks such as answering to the command to pick up a key from a table, to sit on a chair, or to run and open the door. It was also expected to have a minimum vocabulary which large numbers of cases showed that a child of that age did possess. For later years the child was expected to enumerate a series of digits that were read out to it, to repeat simple sentences and to make observations about elementary pictures. As one passed up the scale, there was increasing complexity in the perceptual difficulty, powers of judgment, and the appreciation of the significance as well as the detail of a picture which told a simple story. At the higher years complex judgment was expected, and the meaning of more or less simple fallacies in statements was elicited. Ability to perform mathematical operations was tested by the increasing difficulty of the test question. Binet saw, and saw rightly, that despite the call for economy in time and effort, a small number of standard tests would be deceptive and would lead to faulty assessment, in the same way as the teacher's estimates of intelligence were from time to time vitiated by concentration on some striking endowment or some equally obvious disability. He therefore argued that there should be as many tests as time would allow; they could be multiplied indefinitely in the interest of accuracy. All that was necessary was to obtain from large numbers of subjects and tests a good statistical sample of intelligence at the different chronological ages. When he devised methods for marking the achievements manifest in a set of tests, he was able to say that such and such a child, individually tested, was able to do the tests which statistics proved possible at his age; that is to say, his mental age and his chronological age corresponded, or in the language of mental testing, the *Intelligence Quotient* was 100. If a child, for example, of ten years was, however, only able to achieve pass marks on the tests which an

eight-year-old child could have performed comfortably, then the Intelligence Quotient (I.Q.) was 80. It therefore appeared obvious from these tests applied over a large range of retarded, normal, and gifted children, that there was no sharp line of demarcation between normal and abnormal endowment because there were always found to be intermediate achievements, so that the passage from mental deficiency up to superior endowment was a continuous one. The figures showed, and the figures of all subsequent investigators also show, that the distribution of children over the range from deficiency to superior endowment followed the lines of an ordinary frequency curve. The curve showed that more children were normal or about the mean than were deficient or brilliant, and that there were roughly in any fair sample of tested cases as many endowed children as there were retarded and deficient ones.

It is, of course, true that there may be specific factors for backwardness and imbecility, such as the inherited effects of disease, injuries at birth, ill-health of the mother in pregnancy, psychological and sociological stresses which make for intellectual retardation, acquired diseases such as meningitis, sleepy sickness, glandular defects, and congenital syphilis. But as far as the manifestations of intelligence are concerned, the distribution of degrees of intelligence shows that there are grades, and not true species and varieties of intelligent children. The Binet-Simon scale of tests, as it is called, was by no means perfect. It was primarily suited to French children, and in addition, it was not carried out on a sufficiently large number of subjects to satisfy the justifiable demands of the statisticians. These shortcomings have, to a large degree, been overcome by Professor Terman, who carried out really large numbers of tests on large numbers of subjects, modifying substantially the individual tests of Binet, cutting out those that were inadequate, and adding others. But it became increasingly obvious that these tests merely threw a light upon intelligence as it manifested itself through verbal expression. Most of the Binet and Terman scale tests were tests of intelligence through the agency of language. It must be clear to anyone that power to adapt oneself to environment on verbal lines alone, that is, the ability to

face situations which are expressed in language alone, is no complete test of intelligence. Many of our most accurate and fruitful adjustments to the world are obtained by manipulation of objects; we show our power of grasping relationships of form and function in the absence of words by the way we manipulate objects and relate them to one another with some purpose in view. To apply to an illiterate person purely verbal tests is merely to handicap him without discovering his native ability. Putting, for example, a Polish immigrant child through American verbal tests is obviously to obtain nothing but a negative result as regards intelligence. Even with a working knowledge of a foreign language the ignorance of shades of meaning, or the obtrusion of alien subject-matter, will not only veil intelligence but may arouse emotional moods of fear and even of antagonism which add still further to the handicaps of the examinee and to the difficulties of the investigator in assessing the subject's achievements. There is no virtue like necessity. The extensive tests applied by the American Government to its army recruits in the war, recruits of diverse racial origins, unequally Americanized, showed that verbal tests were in danger of doing grave injustice to the examinees. Necessity, therefore, led to the production of a new type of test, the Performance Test. Such tests are designed to discover, in the absence of language, the power of the subject to understand simple relationships, sometimes independent of some concrete context, although for the very young the relationships are brought out through simple, everyday, pictorial themes. Such relationships are expressed through the construction of simple geometrical forms, or in the substituting of suitable shapes in a geometrical form board, or in supplying the missing parts in an elementary human figure, and in constructing a face from a series of fragments. These tests have proved of inestimable value and are now universally applied even in a supplementary way to the Binet and Terman scales which may not have achieved a satisfactory assessment of a child's intelligence. Above all, the way in which a child attacks these constructional tests, his persistence, his dexterity or clumsiness, his power of profiting quickly by mistakes, or his repetition of

errors, is frequently more illuminating to the total make-up of the child than a simple numerical assessment. In fact, these trials and errors, as well as lack of speed in performing the test, can themselves be scored for the purpose of a numerical assessment. Temperamental peculiarities, therefore, are disclosed in a way that only repeated informal observation of a child can reveal.

We say that these tests measure intelligence. What is Intelligence? On the face of it, according to this method of investigation, it would appear that Intelligence is, after all, only the ability to do a specified set of tests. In an ordinary act of living we make our adjustments to the world around us in concrete situations and not in abstractions. It is the concrete situation which to many people is the driving force making for adjustment. In addition, it must be stated that much success in life is due to our contacts with other human beings, to emotional *rapport* rather than to our powers of relating objects to one another, or in seeing the logic of a situation. Mental tests, therefore, seem on the face of it, at least, to touch upon man's logical endowment rather than to touch upon that part of life which springs from feeling: To overcome the deadlock growing out of the difficulty in defining intelligence, or to make clear what the tests actually measure, Professor Spearman has formulated a theory which basically commits one to no definite belief in an isolated faculty called Intelligence. The theory states that whatever the particular abilities the individual tests measure, there is left an "element which remains always the same in all the abilities of the same individual." Expressed in terms of the nervous system, the mechanism which makes our adjustment to externals possible (it might be stated that "general ability" is non-committally called "g") is the energic endowment of the total brain, and the special abilities are the small motors, as it were, which are run upon the energy derived from "g." Thus, whereas the power of the special abilities (the "s's") vary between themselves, the total energic endowment remains the same for that given person. Much labour, both experimental and mathematical, has been expended upon this line of research. It is this direction in

psychology which has been adopted, pragmatically at least, by all those who work in the field of the measurement of Intelligence. Spearman has realized that there ought to be some relationship between this general ability and other mental operations and endowments, and in consequence many workers have occupied their time in correlating emotional and other factors with general ability. It still remains, however, a subject for general psychological speculation as to what Intelligence really is. It may be a manifestation of the power of Attention, but all the indications of modern researches go to show that some larger conception still will have to be developed which will embrace within its scope, Intelligence, Imagination, and the life of Feeling. The organism acts as a whole, and in the subtle adjustment of man, not only to his environment but to his fellows, Intelligence as measured by the tests we have discussed goes hand in hand with the life of imagination, of feeling, and of instinct.

In the field of education proper the measurement of Intelligence is a matter of everyday practice, and on the borderline between education and the study of disordered behaviour this work is proving of growing importance. The relationship between the nervous disorders of childhood and mental retardation is being slowly made clear by these investigations, and the study of delinquency has received a new impulse through their agency. But as our later observations will make clear, the study of Intelligence alone does not altogether dispel the fog that still envelops the study of disordered behaviour and delinquency. We might venture further and say that the highest endowments of man as manifest in creative endeavour, in art, in literature, and in practical affairs, do not receive their full explanation in the study of Intelligence in isolation.[1]

One of the healthiest signs in modern psychology has been the convergence of the objective study of behaviour and of Intelligence in the investigation of the life and mind of the child. The orientation of all the sciences since the epoch-making discoveries and theories of Darwin has been in the direction of

[1] Professor Spearman has, however, attempted to treat of Creative activity on the basis of his Theory of Cognition.

the study of origins, and the consideration of the processes of development in the light of the dynamic relationship of events in the life of the human organism. Physics traces the development of states of matter from the electron to the rich variety of physical forms, in addition to the way in which matter and energy are related to one another. Astronomy speculates on the origin of worlds and their hypothetical destinies, as well as studying celestial mechanics. Psychology is, perhaps, the field in which the idea of development presents its most fascinating problems and promises. Behaviourism claims the infant and the child as its most legitimate object of study. Arguing from the objective study of animals that we can observe only actions and inner physiological events, it starts with the babe as a coherent bundle of reflexes, that is, as a system of responses to external stimuli. Irrespective of what inherited mechanisms the infant may possess, it is witness to the possibilities of complex behaviour which a given external world can impose upon the organisms. The child's reflexes are, according to Behaviourism, few and simple, and the world of physical and social variety merely conditions these reflexes, building upon these simple, elementary nerve structures or mechanisms the complicated patterns which constitute the be-all and end-all of the life of action. In this life of action, language, or speech, habits, as they are called, are the fundamental links in the mental life of a human subject in its social relationships. The child is the physiological father of the man, and whatever conditions are imposed upon the child become the base plan of the future man and woman. Language, just like any other cerebral activity, is expressed by or actually is nothing more than the conditioning of movements of the larynx and the associated mechanism of articulation. When we speak, we do nothing more than bring into operation movements of the speech apparatus which have as their deeper connections movements initiated by the cerebral cortex and nothing else. There is no such thing as consciousness but only speech habits which are the accompaniments of larger motor adjustments to environment and to one another. As a laboratory formula for understanding the simple activities of the child in its elementary adjustments

to life, this approach is salutary as well as profitable and economic in that it prevents at the first stage of our understanding of life any intrusion of mystical ideas and sentimental prejudices into what is already a difficult problem, but it does little more than describe a mechanism, the detailed reflex structure of which is itself a hypothetical structure which research imposes upon us. Professor Pavlov, who, as a result of his brilliant researches on the behaviour of animals under very specified conditions, originated the theory of Conditioned Reflexes as a basis of behaviour, fails in the end to confine himself to purely physiological or rather mechanistic categories. He too, perhaps unwittingly, had to admit temperamental differences in his experimental dogs, and above all, fell into the teleological groove when he was obliged to speak of *Search Reflexes* to explain certain complex forms of behaviour. It would appear that if so careful a worker engaged in a narrowly defined laboratory technique on elementary material in simple situations is obliged to use terms which are not strictly physiological, then the situation which produced this lapse may be of nature's own making, and that the category of purpose underlying physiological processes has to be admitted at the outset. Much brilliance in laboratory technique and argument has been exhibited in the construction of the mechanistic standpoint, but the constant reiteration of the statement, "Mechanisms yet unrevealed or too subtle for our present instruments will be forthcoming," casts a suspicion upon the point of view. Until logical statement gives a satisfactory non-psychological solution of what we understand by purpose and interest in living things as we see them behave, psychology will be justified in maintaining its specific vocabulary for explaining even such elementary behaviour as we witness in the life of animals and children. It must be conceded, however, that the experimental method so carefully worked out by the physiologists, and the statistical assessment of results, must remain the method of observation of Behaviour, and even the so-called inner life of man will need an analogous technique in order that its findings shall fall into the framework of scientific method. But it will be left to psychology with its vocabulary to stand in the rôle of critic and

judge of the ultimate findings derived from the methods of the laboratory. Theories of inheritance alone will not explain the early appearance, for example, of temperamental differences in behaviour, or the engaging obstinacy with which quite young children and animals, too, pursue their activities. Organisms, however simple, do not really react to environment as a spring reacts to an external force. Living things throughout the whole range of biology tend to meet environment and not merely to suffer it. It may be that ultimately living matter, too, has its relentless laws, but they are such that for their complete understanding a new vocabulary, a new language, must be used for their complete expression. Without denying one fact derived from laboratory experimentation, or statistical analysis of large numbers of actions, psychology will still stand as a critique of these findings in terms of its essential vocabulary, and of this essential vocabulary the concepts of purpose and end seem to be irreducible terms. Purpose and end are not used in this connection to imply that psychology throws a light on ultimate purpose, but that in the life of the organism the drive behind activities seems to be an irreducible concept. In the study of dynamic psychology, which is the main concern of psychopathology and the investigation of the Unconscious, the concept of purpose as vested in a "drive" seems to be an irreducible necessity.

The Psychology of the Unconscious

The idea of the Unconscious was mooted by thinkers for many years before Freud, who has been responsible, more than any other pioneer, for bringing it into the forefront of psychological theory. The Unconscious has been implied, if not explicitly stated, in folk proverb and in literary aphorism for many centuries. By the concept of a dynamic Unconscious, a world of mental forms, complex patterns outside awareness yet profoundly influencing consciousness, psycho-analytic research has certainly enriched the literature of psychology. Although there have been in the work of Jung and of Adler deep dissensions from Freud, the main body of their doctrines

is coloured indelibly by the doctrine of the Unconscious. That a man is revealed in his cups, that a slip of the tongue will reveal the truth, that a dream has some reference to deep emotional dispositions, has been known, if grudgingly admitted, in the centuries of literature. People have always felt the uncanniness yet the glimpses of truth in the words of madmen. They have been strangely stirred by the action of witches, and by the random sayings of fools and children. Yet none of this scattered lore relating to the unusual in the mental life was ever collected and treated scientifically for the benefit of psychological advance until recent years. This, then, can be regarded as one of the primary contributions of the so-called new psychology. In giving a coherent explanation of the unusual in human thought and behaviour, it has been found necessary to bring into being the concept of an Unconscious, even if it is unable directly to describe its actual topography in relation to conscious awareness and the action of the nervous system. This does not presuppose that no attempts have been made to put the Unconscious into the scheme of human life or even to relate it to the events in the nervous system. Pre-eminently the Unconscious is a conception which makes possible the handling of certain phenomena which would not be clearly understood in the absence of such an idea. How do we come by a knowledge of its workings in itself and of its effect upon conscious awareness and behaviour? The work of Janet, of Morton Prince, and of Freud and Jung arose from the study of those abnormal states of mind and behaviour which occur in those who suffer from hysteria, somnambulism, so-called divided personalities, and from a study of obsessions and of fixed ideas. Latterly the application of the idea of the Unconscious to the study of the major forms of insanity has led to an extension of the theory and to a unification of all facts relating to disordered behaviour. Freud and Breuer discovered that when a person under hypnosis was allowed to speak, long-forgotten episodes were related, complicated desires and fears which did not appear in consciousness were made manifest during the hypnotic sleep. It was found that these forgotten events and desires and fears were somehow related to the

symptoms from which the patient suffered. It was further found that the hypnotic method was by no means the only means of bringing to light this forgotten material. In fact, it was found that if a patient in a state of relaxation were enjoined to give vent without let or hindrance, without criticism, to every thought and feeling that came into the mind, in time many forgotten episodes came into consciousness from the remote past. They seemed to come from some hidden realm sometimes as if they had not merely been forgotten, but that they had never been formulated in words by the patient at all. The physician, during such a procedure, sits by and endeavours to direct an impartial and unprejudiced attention to the material as the patient gives it, quietly noticing every resemblance and difference until connections force themselves upon him and upon the patient, leading to provisional conclusions which may be maintained or rejected or re-stated in the light of further material as it emerges. This method of Free Association, as it is called, is the key-method of psycho-analysis, and it is not to be confused with the body of doctrine which Freud has deduced from the method. It is obvious that apart from these resulting theories, the method itself as a scientific instrument stands or falls with the acceptance or rejection of psychological determinism. Unless every event which emerges is part of a causal chain of related phenomena independent of some free agency, no conclusions can legitimately be drawn from the procedure. As many other schools of psychology accept some form of psychological determinism as a working hypothesis, we need not pause to examine the validity of this scientific tenet. Some form of determinism is the *sine qua non* of all scientific methods which have causal relationship as their fundamental principle. Arguments for and against Free Will belong rather to the field of speculative ethics and philosophy, and it is left to these mental disciplines to decide whether life is ultimately free in the light of psychological and other fields of inquiry.

Persistence in the exploring of these Free Associative mental elements does not, as one might suppose, result in a mass of incoherent material, but in the gradual emergence of types of

relationship between facts in the mental life which have apparently been submerged or have never been part of a verbal mental content in consciousness. It has been found that the earliest years of our lives are foundation-stones to all subsequent development, and that early influences, desires, and impressions bear a causal relationship to the conscious thoughts and overt acts of our adult lives. This may sound like a truism if it is accepted as a general formula and nothing more. What is implied, however, in this statement, in so far as it grows out of the psycho-analytic technique, is that these early influences are far from the world of consciousness and have a dynamic relationship to everyday life, and are not merely substructures. They are in their peculiar way the very life-blood of consciousness. Psycho-analysis alleges that this method of reawakening the past and of bringing to light urges and struggles which have never perhaps been put into words lays bare not merely the events in a personal history but the lines along which our instinct and emotional life have developed, come to fruition, or have been inhibited in their aims. It exhibits the way in which these instinctual trends have been all along deflected from the path which, in the absence of a variety of prohibitions of a familiar and social character, would have assumed a different, nay, a directly biological trend.

According to psycho-analysis the sexual urge starts in its primitive and ill-defined way in childhood as a diffused sensuality. This sensuality is of a twofold character: it is expressed not only in an urge or drive which has a forward direction, but is also manifest in what is called the Pleasure Principle. This principle refers to the propensity of the child towards the maintenance of all experiences which give a pleasant feeling tone. For example, the act of sucking at the breast, while satisfying a nutritive or alimentary urge, is accompanied by a pleasurable feeling which the child desires to prolong. The dependency upon the mother in a wider physical sense is also accompanied by a pleasurable feeling tone, a state, the maintenance of which is desirable. In the process of development, when dependency upon the mother for warmth, nutrition, and comfort becomes less urgent, this clinging to pleasurable

sensations, or what is called hedonic interest, gradually gives place to a sense of external reality. Two forces are at work in the child, the forces of biological growth which make for increased separation, independence, and consciousness of self as different from a non-self, and the desire or longing to retain the state of pleasurable quiescence which is the effortless existence on the bosom of the mother. Pleasurable sensations have been proved to be concentrated upon, if not limited to, certain areas of the body, of which the mouth and the genital organs are the outstanding examples. In the course of development these so-called erogenous areas become incorporated with, or merged into, the developing sexual function which comes to fruition at puberty. Long before that time, however, according to the Freudian doctrine, the pleasure-giving area or erogenous zone is the genital apparatus. By puberty, genital primacy, as it is called, should be firmly established in the normal case. Age-long social tradition, however, has played upon the dependency of the child, upon its sensual indulgence which grows out of this dependency, and ultimately upon the genital interest. The prohibitions and inhibitions which entangle the whole of sex life in the history of man are typified in the attitude of the child towards its parents. In both father and mother, the child envisages not merely examples of adult life in all its supposed strength and glory but also the first glimmerings of sexuality. For what, as we have shown, becomes specified in the sexual apparatus has before been diffusely experienced in other regions of the body; in fact, all over the body during the period of dependency upon the mother. This primitive sexuality at first attaches itself to the parents, usually of the opposite sex, and from this period of attachment all the inhibitions which long social tradition has imposed have their origin. From this first emotional impasse, that is, the prohibition placed upon sensual gratification, the first deflections of the mental life take place.

Freud, independently of all other observers, has worked out from his own self-analysis and from the empirical observation of his patients during long hours of free association, the complex network of mental entanglements that has formed as a

result of the forces of prohibition, inhibition, or repression. As a result of deeper research, he was later obliged to modify or develop his original views as to the sexual nature of the repressions, and also as to the nature of the repressing forces, by including the activities of the self as an agent in the production of repression. From the first appearance of repression, and the effort to overcome the strain which repression produces, some agency is proved to be operative in producing the forgetting or the compensatory behaviour. This agency is the self acting as the mentor of behaviour and thought. This repressing force appears, however, in the external life of the child as the parents, usually the father. To the child, the father is the source of authority, and, therefore, of fear because of punishments that his authority can impose. He becomes, also, a standard of behaviour to the child—the source of all ideas of excellence in conduct, which develops paradoxically *pari passu* with the notion of guilt for such behaviour as the parents censure, or which they might censure. In so far as the authority of the parent becomes the standard of excellence, he is absorbed into the self as an ideal to live up to, but in so far as he is also the source of authority and the centre from whom the conception of guilt arises, this absorbed new self, or ideal self, becomes an inner source of criticism of behaviour, a conscience, a still small voice. This process of self-development on what we might call the primitive ethical side does not necessarily take place entirely on the level of awareness. It is largely, if not entirely, an unconscious growth. Not that the elements from which this growth has arisen have not been a part of consciousness, but the organization of it into an internal system, a super self, takes place by a process of unconscious organization by biological efforts of the organisms at harmonious adjustment to the world. It is an attempt, in short, to become a more complete self, a self which will now contain not only its own native endowments, but all the good of the outside world. To the child, all the good of this outside world has its highest expression in a beloved and respected parent. It becomes the most potent element in the unconscious life and it is because of this fact that the dictates of conscience, of the super self,

become so tyrannical because unseen, the mentor that neither slumbers nor sleeps, the critic not only in our waking hours but the mentor in the dreams of the night. In the dream it seems to watch over our activities, filling us at one time with terror and at another acting as a blessed anodyne which creates in dream-images the realization of splendours of self-expression which the waking life does not offer or permit. It makes us in moments of remorse cruel to ourselves. Though ourselves unaware of its force, it makes us over-sensitive to the moral lapses of others, and may in further stages make us project on to others the very shortcomings of which we only feel the vaguest stirrings in ourselves. At times, on the other hand when our deeds seem to satisfy the super self, or when we escape from its tyranny, the greatest feelings of elation, freedom, and sometimes of truculent over-confidence come to full fruition. This fruition may express itself in one person in a maniacal outburst of self-confidence and self-esteem, and in another in some creative urge which makes him overcome obstacles which before were insuperable. Thus, in Freud's own words, man is, in his deepest nature, not only essentially immoral but most essentially moral also. Dependence upon the parents, particularly the mother, in infancy and in childhood leads on to love and admiration of such intensity that we fail to understand the love of external persons in any light but a purely emotional one built upon and anchored to this primitive attachment. This bond of love becomes the nucleus, the core, not only of that non-rational *rapport*, which is called suggestion, but of the process of falling in love in adult life. Falling in love in adult life should be governed by pure object-choice, that is to say, our attachment should be purely conditioned by the object as our instinct of love in its working has chosen it, and not by some primitive standards from which we have failed to emancipate ourselves. The operation of suggestion in this sense produces a condition in psycho-analytic procedure which is called *Transference*. It is the disentangling of the childlike, primitive strands of the transference motives in the life of the patient which constitutes the central theme and aim of the psycho-analytic treatment. The rôle that the parents

have played in the lives of patients becomes a source of the positive and negative transference upon the condition itself. It is the scientific exploitation and resolution of these positive and negative phases which constitutes the success or otherwise of the treatment, for it is considered, according to the Freudian discoveries, that the symptoms of neurosis are largely the unsuccessful efforts at solving the love conflicts which the patient has suffered in relation to the parents.

Freud's theories would be extraordinary enough if they led merely to an understanding of the emotional tangles of the mentally sick, but in the course of an analytical investigation such deep layers of the mental life are laid bare, so many general functions in the mental life seem to find their explanation, that it was not unreasonable to suppose that its discoverer would have applied its special findings to more general psychological and sociological problems. This Freud has done, but not without arousing doubt and opposition in the minds of the sociologists and moralists who have pursued a psychological course along the paths of consciousness rather than in the deep recesses of the heart. We have seen how an individual moral problem is capable of elucidation by an exploration of the unconscious processes involved in the development of the self. Why not then apply the principle to morality and to religion? By the application of his special theory of mental conflict arising in the family life, Freud has produced a social theory and a suggestive critique of religion and civilization.

A theory which digs its roots into the heart of the mental life of individuals cannot stand unless it finds some corroboration in the little-understood practices of mankind. It is not strange, therefore, that Freud and his followers have driven the psycho-analytic plough into the soil of folk-lore, fairy tale, myth, and even humour. In each of these fields, dark undergrowths formerly only described have been laid bare and illuminated with a new light which not only explained individual phenomena, but also brought out general relationships of a psychological character in the culture of man which were before never contemplated. Parallels, for example, have been

suggested between dreams and myth, between the obsessional acts of neurotics, and the rituals of religion, between the hallucinations of the insane, and the visions of saints and martyrs. At the present stage of the development of the psychology of the Unconscious, we are confronted with a powerful agent, and secondly with a group of concepts which allow for the tentative establishment of parallels. Dr. Jung has gone further in stating that the Unconscious is not only part of the individual mental life, but is a partial expression of a universal Unconscious which all men share alike and in which primordial images or archetypes of thought are to be found which express in symbolic form the universal cravings and aspirations of man. It has been suggested that if there are erroneous deductions in the analysis of patients, then their extension to the field of sociology and folk-lore gives rise not to a crop of new ideas but to a tangle of evil-smelling weeds. It is stated, in criticism, that if the same concepts are applied to the sociological field as are applied, and perhaps not discovered, in individual psychology, the same results will accrue. It is therefore incumbent upon the student of this field of psychology to satisfy scientific scepticism by fulfilling two conditions: (1) to multiply the analysis of cases a thousandfold, and (2) to introduce into psycho-analysis some such experimental method with controls as we see in operation in the field of formal psychology. In the nature of things, the details of an analysis cannot easily be conveyed to a third person, nor can an analysis be successfully carried out in the presence of a critical third person to whom the transference situation conveys little. It is difficult enough to maintain a train of free associations in the presence of a trusted physician, let alone in the presence of a third party whose interests are critical and not part and parcel of the analytic procedure. The future of psycho-analysis as a scientific method rests, therefore, on the future application of the experimental, if not of the statistical, method. It would seem that at no distant date a liaison will be established between those who measure intelligence and assess temperament on psycho-physiological lines, and those who explore deep psychic motives. This liaison will probably be established in the first place by those who are

engaged upon the experimental observation of emotion and the assessment of temperamental differences. Already those who are working on psychopathic and delinquent children daily witness the vitiating effects of emotional disorder and instinctual disturbances upon the manifestations of intelligence. This may be a problem which will throw no light upon the truth or falseness of the psycho-analytic procedure, but it will show at least the ways in which overt behaviour, as manifest through intelligence, is influenced by disturbances in the emotional sphere. In other words, we will have an indirect method of applying experimental procedure to a branch of psychology which at present does not appear to satisfy the canons of the experimental psychologist. For some time to come, psycho-analytical findings will have to be expressed qualitatively, but there is reason to hope that repression which sometimes expresses itself in certain intellectual shortcomings, in perseveration, and in fatiguability may be amenable to measurement. In fact, work is at present being done relating the phenomenon of perseveration (or the persistence of past reactions into the present, leading to maladaptation) to certain types of mental disorder such as dementia praecox. Important links will be established between emotional disturbances and the phenomena of repression. These relationships will be established rather on the physiological side in the study of the internal secretions. In addition, the psychic and physical links will be further strengthened in correlating the electrical changes in the body with suppressed memories and their abreaction on the physiological level. In this specialized field—still in the realm of experiment—we may hope to see interesting connections established between the conditioned reflex and the so-called psycho-galvanic reactions. This may, perhaps, enable us to see more what one feels has hitherto been neglected, that is, the part that emotion plays in the establishment and breakdown of conditioned reflexes.

The general study of types in their physical and mental aspects has been the subject of much study, especially in Germany. Large groups of mentally afflicted people are described as belonging to definite reaction types, that is, they

tend to react to environment and to stresses of a psychological nature in certain fairly circumscribed ways. These reaction types seem to correlate fairly closely with types of physique. Here too, therefore, the correlation of intellectual, emotional, and physiological factors, should produce a rich harvest firstly for psycho-pathology and secondly for general psychology and education. For is it not obvious that when we have physical phenomena, measurement is our first obligation? And as intelligence is subject to mathematical estimation, as we have shown, the correlation of intelligence with physical and mental types will bring its reward in further psychological enlightenment. Study of the mental types is an introduction to the field of psycho-pathology and deep psychic motives. We therefore have the promise, in this method of correlation, of further psychological enlightenment over a wider and wider field.

Deep psycho-pathological research gives us the history of our instincts and their effect upon behaviour. It also shows how the vicissitudes of those interests will vitiate intellectual development. In so far as this branch of psychological study casts its roots into the deepest strata of the organism it must somehow be related to the processes which physiology is making clear to us. Neurology and physiology have demonstrated that the life of action is connected with structures of the brain, and that the expression of our emotions is dependent upon the activity of our glands of internal secretion and their nervous connections. The organism works as a whole, and emotion must have some connection with the machinery of the central nervous system. We know that the central grey-matter, or nuclei, of the brain is associated with the expression of the instincts, and that the feeling tone accompanying all experience has some relationship with this region also. Emotions are but the mental and physical events which take place when an instinctual act of adjustment is about to be fulfilled, or when an instinctive act is delayed or even checked. An unimpeded action making for the harmonious adjustment of an organism is scarcely characterized by an emotional accompaniment at all. At most

a satisfactory act of adjustment is accompanied by a pleasurable feeling tone. The various disturbances, therefore, that we meet with in the nervous disorders both major and minor are the emotional disturbances and their *sequelae* resulting from the impediments which natural acts meet in the course of their fulfilment. The history of such disturbances, of such partial fulfilments or non-fulfilments, is of first importance to the student of mental disorder. By laying them bare by the process of analysis, or by whatever technique we employ, we are able to release the natural activities from their entangling impediments, usually primitive impediments which bear no healthy relationship with the present situation. Most of these entanglements take place in the early years of mental plasticity when the untamed creature is broken into social ways and willy-nilly accepts the bridle of authority. Who knows that the very concept of the Golden Age may be but an iridescent veil created by past desires through which we look back upon the imagined halcyon days of unimpeded freedom. It is a false freedom because by careful education of a healthy, elastic mentality and a perfect body we are able to bear the pull of the bit in our mouths and to face the real world with which we are biologically destined to hold commerce. The most fretful Arab steed accepts the bridle and with it accepts the joys of freedom in captivity. "To welcome each rebuff that makes earth's smoothness rough" is the biological destiny of every creature, and it is the avoidance of this destiny making us one with the universe of things around us which leads to unhappiness and disease. Such then are the rich complexities of man's nature which dynamic psychology has disclosed.

Looking down from above, as it were, we gaze with awe and sometimes with a feeling of revulsion at the relative lowliness from which we have climbed, but when we explore the devious paths which we have painfully trodden, and the heights to which we have climbed, we can wonder at man's power to suffer change and to accept its transformations. Perhaps, as Freud suggests, cur cultural achievements are largely illusory and the truer path is to face reality and to free ourselves ultimately from those fantasies and mental entanglements

which ages of social prohibitions have given us for our comfort and solace.

The next few decades of psychology will hold further problems for the scientist and amongst them will still be this one: Is the world of scientific analysis less illusory than the cultural illusions which our mental and social struggles are said to have created? Will deep psychology show that although Freud has laid bare the illusory elements in the religious attitudes and practices of man, he has not disposed of that *rapport* with the world—that sense of communion with Nature, which has been described as the Religious Experience? Perhaps this experience, vague though it is because of its emotional core, is yet as much a reality as the logical shapes which the scientific or intellectual activity has made clear to us.

In addition, we may ask, does the scientific activity do anything more than describe in terms of logic what the artist and the poet sense in terms of emotionally charged symbols? To come to grips with reality as a whole, psychology for its complete task must accept the symbolic expressions of both Science and of Art.

CHEMISTRY AND RADIATION

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IN the sensuous world as perceived and interpreted by us there appear to exist two very important types of relationship: structure, a relationship in space, and action or activity, a relationship essentially involving time. Although in the "space-time" (four-dimensional) system of modern theoretical physics these two types of relationship are blended or combined, we may content ourselves for the present by regarding them as separate. Now in the sensuous world as defined above we conceive that there exist two very important things, namely matter and radiation. We shall not go very far wrong if we say that physico-chemical science is greatly concerned with the two general relationships as affecting these two things, i.e. with (*a*) the structure and activity of matter (including its related "fields"), and (*b*) the structure and activity of radiation. To complete this list, however, we must add a third very important category, (*c*) the reciprocal interactions and relationships cf matter and radiation.

This rather rough-and-ready classification does not presume to any fundamental or philosophical value. It may, however, serve to give us a general idea of the scope of much modern physico-chemical science, and to define and de-limit the subject of this lecture, which will be concerned more particularly with certain aspects of (*c*).

By the term radiation we mean radiant energy, that is, energy detached from matter. It is one of the great discoveries of modern physico-chemical science that radiant energy possesses (inertial) mass, i.e. one of the essential properties of matter, and that matter itself may be expressed in terms of energy. Thus if m denote the mass in grams of a particular piece of matter, and c the velocity of light in centimetres per second, then the total intrinsic energy E of this piece of matter, expressed in ergs, is given by the Einstein equation $E = mc^2$.

Similarly, if there exists in a given enclosure a quantity of radiation whose energy is equal to E ergs, the mass of this radiation will be E/c^2 grams. If V be the volume of the enclosure in cubic centimetres, then the radiation in the enclosure will possess a density of E/Vc^2 grams per cubic centimetre. Matter and radiation can therefore be interrelated by means of the concept of energy, in the sense that we can state numerically the energy corresponding to the mass of a given piece of matter and the mass corresponding to the energy of a given quantity of radiation. We shall find these considerations of great importance at a later stage of this lecture.

Imagine yourself, after a long moorland walk, resting on the heather-clad slope of a hill during a bright summer afternoon in August. You feel the gentle pressure of the sun-warmed heather against your body, cool airs wafted up from the loch below fan your face and hands, whilst out of the serene sky flecked and fleeced with white the gracious radiance of the sun streams down upon you and fills your spirit with a deep contentment. You are pleasantly and deliciously alive, and so also are your quiet companions, the green heather plants. On that lazy summer afternoon you experience the joy of life, and you may perchance ask yourself for what parts matter and radiation are cast in the play of life. You realize that life is a sort of process, an activity in the stream of time, and one, so far as we know, closely associated with matter. Physiological science teaches us that living organisms are special types of co-ordinated structure, enduring in time with a special type of co-ordinated activity. Life is, in short, a very special sort of structure-activity, a specific type of process. When, after a good breakfast, we sally forth in the morning and spend a day of activity, we may perhaps be inclined to think that we are independent and self-sufficing organisms. A moment's reflection, however, teaches us that without food we should starve and die, and that, even if we had plenty of food, we could not go on living without a constant supply of oxygen in the air we breathe. The life process cannot go on independently of the external environment of the living organism. What is it in this external world that is necessary to sustain

the process of life? The answer of physico-chemical science is that there must exist in the external environment energy that is not in equilibrium, i.e. energy that is still transformable and available for doing work. Consider the case of a motor-car. It is a certain type of structure, but it will not develop activity unless it gets petrol and oxygen. Petrol plus oxygen represents chemical energy that is potentially active, potentially transformable into heat and work (together, of course, with the carbon dioxide and water, the material products of the chemical reaction). Now I do not suggest that a living man is a structure-activity in any way comparable with a motor-car. Nevertheless, viewed solely from the energy aspect of the environment, there is a close analogy. The man's food plus oxygen also represents chemical energy that is potentially transformable into heat and work. If a beefsteak (suitably dried, of course) couldn't be made to burn in oxygen, I doubt if we should find it very satisfactory.

These preliminary considerations may prepare the way for an understanding of one of the greatest discoveries of science, namely that radiation is the great Sustainer of Life on this planet. I take off my hat to the worshippers of the Sun. Equally I take off my hat to the farmers. They are the Shepherds of the Light, and the priests in the radiant Temple of the Sun. I believe the nations of Northern Europe have a festival about the time of the summer solstice. If so, no doubt it derives from those ancient times when men worshipped the Sun. You may call me a pagan if you like, but I feel it would be a great thing if all we town workers of to-day were required to make a religious pilgrimage to the tilled fields and green pastures once a year, say when the first breath of returning Spring brings its fragrance to our nostrils, or when the sun rises on Midsummer's morn, and, falling on the bosom of Mother Earth, were to offer thanksgiving for that bountiful conjunction of Sun and Earth, of Radiation and Matter, which sustains our life.

It is the green plants that "bottle the sunshine," i.e. that convert a part of the radiant energy that falls on them into potential chemical energy. These plants contain several pigments,

the chief of which is the green colouring matter called Chlorophyll. By means of these substances and under the influence of light, the living green plants are able to convert the carbon dioxide and water vapour in the atmosphere into sugar and oxygen. Sugar and oxygen contain more potential energy than carbon dioxide and water vapour, this excess of energy being derived from the sun's radiation. We can easily understand that when we reflect that sugar will burn in oxygen, producing heat energy, and, under suitable conditions, work. The chemical products of this reaction are the original carbon dioxide and water from which the sugar and oxygen were derived. This storing up of potential chemical energy, derived from radiant energy, by the green leaves of living plants is known as photo-assimilation or photo-synthesis. The action is represented by the energy equation:

$$\underset{\substack{\text{(carbon}\\\text{dioxide)}}}{6CO_2} + \underset{\substack{\text{(water}\\\text{vapour)}}}{6H_2O} + \underset{\substack{\text{(energy from}\\\text{sunlight)}}}{\text{674,000 calories}} = \underset{\text{(sugar)}}{C_6H_{12}O_6} + \underset{\text{(oxygen)}}{6O_2}$$

From this equation we can easily calculate that for every pound of sugar produced by the plant a quantity of radiant energy is stored up sufficient to heat 37·44 pounds of water from the freezing point to boiling point. From the point of view of living things on this planet, this action is a fundamental one, the most important relation between radiation and chemistry known to us. For, as Thomas Henry Huxley once said, the green plants are the fundamental capitalists of our world. Animals live on the potential chemical energy, the capitalized energy, stored up by plants. If it were not for the capital stored up by these silent green accumulators of potential energy, the generous sunshine would run to waste and life on this planet would probably come to an end.

We may ask ourselves the question, how efficient is this process of transformation? The recent researches of Professor Otto Warburg, of the Biological Institute at Dahlem near Berlin, have given a satisfactory answer to this question. Sunlight, as you know, is a mixture of different sorts of radiation, corresponding to the various colours of the spec-

trum. The following table gives the results obtained by Warburg:

Spectral Region	Percentage Efficiency
Red	59
Yellow	54
Green	44
Blue	34

The figures in the second column denote the percentage of the radiant energy (corresponding to the part of the spectrum named in the first column) which is converted into chemical energy. The efficiency is greatest in the red and yellow, though, curiously enough, the absorption of light by the coloured pigments (chlorophyll, xanthophyll, and carotene) is greatest in the blue (Warburg's experiments were carried out with a minute green alga called chlorella).

Let us pause for a moment to consider this fundamental process from another point of view. The energy radiated to us by the sun comes from its surface layer. An analysis of this radiant energy shows that the temperature of this surface layer must be about 6,000° C. The average temperature of the earth's surface is in comparison very low. The conditions are therefore such that the relatively cool surface of the earth is, during daylight, bathed in a stream of relatively high temperature light. This relatively "hot" radiation is *not* in equilibrium with the cool surface of the earth. Here, then, we have another striking case of energy out of equilibrium, and hence the possibility of a partial transformation of this energy into potential energy. If the surface of the earth could be kept comfortably warm, but entirely deprived of this bath of high temperature light, the possibility of a storage of potential chemical energy by green plants would disappear and life as we know it would come to an end. The sun is the Life Sustainer because his surface is sufficiently but not too hot, and because we are far enough away from him to be sufficiently but not too cool.

Our present highly organized civilization is largely dependent on the utilization of pre-formed, though limited, stores of potential chemical energy. The light, heat, and power we use to-day are derived mainly from coal and oil. The coal and oil in themselves do not provide us with any source of potential energy. This source is derived from the fact that coal and oil are not in equilibrium with oxygen. Hence coal *plus* oxygen and oil *plus* oxygen are our real sources of potential energy that can be partially transformed into work, heat, and light. The mechanisms and machines of our modern civilization are therefore like animals. They are the users and spenders of a limited potential energy which they have not produced and which must be supplied to them. They are not like the green plants which, in the main, are storers of potential energy.

This indictment of the material side of our present civilization does not strictly apply, however, to the work of the hydro-electric engineers, i.e. those who convert the potential energy of water lying above the general sea-level into electrical energy, because this supply is continually replenished. It is the heat derived from the relatively hot radiation of the sun which constantly lifts, by evaporation, the cool water of the oceans up to the highlands, whence it tends to flow back to the sea. This source of potential energy will remain available to us as long as the sun remains sufficiently hot and there are highlands above the sea. The astronomers assure us that we can count on the sun for thousands of millions of years to come, whilst the geo-physicists give us the (perhaps rather fearful) information that we may expect in the future history of the earth the throwing up of some sixty new mountain ranges. Those excellent people, the hydro-electric engineers, are therefore doubly assured of a high destiny even in the very distant future. Some two or three thousand years from now there will probably be no coal or oil left. How will the inhabitants of this planet then get their light, heat, and power? We may suggest the following sources of potential or co-ordinated energy:

1. The potential energy of water lifted above the general sea-level by the sun's heat (as utilized at present).

2. The potential energy of water lifted above general sea-level by the tidal action of the sun and moon (or possibly the kinetic energy of moving tidal water).
3. The internal energy of the atmosphere, arising from differences of air pressure at different parts.
4. The potential energy of natural plant products which will burn in oxygen, or of substances derived from such plant products by chemical means.
5. The potential energy arising from differences of temperature in the earth's mass or in the deep oceans.
6. New photo-chemical methods of storing the radiant energy of the sun in the form of potential chemical energy.
7. Sun-heat engines using the heat derived directly from the sun's radiation.
8. Aero-electric engines utilizing the differences of electrical potential in the atmosphere.
9. Geo-electric engines utilizing differences of electrical potential in the crust of the earth.

This list might be extended, but you will probably think it sufficiently long and perhaps in some respects sufficiently fantastic. I have drawn it up on the assumption that the idea of a utilizable sub-atomic potential energy is a gambler's dream. Our best physicists are willing to lay long odds against this chance.

You may be inclined to ask me one question. How will our scientific descendants obtain the petrol and oil required for their motor-cars and aeroplanes? I refer you to (4) and (6). If you are not satisfied with this answer, then I make the following dangerous prophecy. Of the chemical element carbon existing in our planet when the latter was a glowing liquid mass newly drawn from the surface layers of the sun, most of it, as a light element, came to the surface and was oxidized to carbon dioxide as cooling proceeded. Relatively little of this primeval carbon dioxide has been converted into the coal, oil, and other organic matter, living and dead, that exist to-day on or near the surface of the earth. Great quantities of it are

to be found, though in a very dilute state, in the air and the oceans. It is not so often realized what enormous quantities are locked up in chalk and marble, and in the limestone and dolomite of vast mountain chains. The scientific chemists and engineers of those future ages may adopt the following plan. They will certainly generate electrical energy. By means of this they will be able to electrolyze water and obtain hydrogen gas. The electrical energy can also be converted into intense and localized heat, and this can be employed to decompose chalk, limestone, and dolomite, and thus to set free the locked-up carbon dioxide. Given carbon dioxide, hydrogen, and heat, posterity will find no difficulty in producing liquid motor fuels suitable for cars and aeroplanes, for the necessary method is known to us to-day.

Another problem, closely related to the question of future supplies of potential energy for power, heat, and light, may be briefly touched on here. If the green plants stopped work, would all life on this planet necessarily cease? Or, to put the problem in another way, will our scientific descendants be able to manufacture synthetic food in sufficient quantities? Consider the food required by ourselves and our domesticated animals. Besides water and certain mineral salts, we require fats, carbohydrates (starch and sugar, for example), proteins, and those essential substances known as vitamines. It seems quite possible that chemists will be able to manufacture the necessary fats, carbohydrates, and proteins, starting from such simple inorganic substances as carbon dioxide, water, and atmospheric nitrogen. Some progress has been already made in this direction. The chemical nature of the vitamines is still shrouded in considerable obscurity, but there seems no reason to doubt that this problem will be solved and methods devised for producing these substances.

It does not follow that superior mammals like ourselves would be entirely dependent on this synthetic manufactured food. A cow, for example, is an apparatus for manufacturing milk and beef from grass. If we could manufacture synthetic food sufficient in quality and variety to sustain the life process of cows, and induce them to eat it, then we could still have

our milk and our beefsteaks. A similar process with hens would lead to fried eggs and roast chicken. A little garnishing of this diet with supplementary synthetic vitamines need cause us no discomfort. So the main problem might reduce to that of manufacturing synthetic fodder sufficient in quality, variety, and amount for our domestic animals. I must confess, however, that the want of bread, fruit, and vegetables would be a very grave discomfort, and perhaps something much more serious than that. We need, however, have no fear that the green plants will stop their beneficent work of manufacturing food so long as the sun continues to shine bravely and there is plenty of water and carbon dioxide. On that matter, as I said before, the astronomers give us—bar improbable accidents—a shrift of thousands of millions of years. That masterly scientific romancer, Mr. W. Olaf Stapledon, in his recent book, *Last and First Men*, traces the future history of the human race for the next two thousand million years. Mankind is driven successively from this earth to the planet Venus, and from Venus to Neptune. Mr. Stapledon, however, takes poetic liberties with the moon and the sun, which a maker of romantic myth is perfectly justified in doing, and which he does surpassingly well. His liberties are perhaps not impossible ones, but I do not think the astronomers would regard them as probable. So the future difficulties of mankind seem likely to constitute a drama to be played out on this old earth.

Let us now turn from these affairs of human economy and economics, from science applied to our needs, again to science itself.

Is radiation as old as, or older than, matter? That is a question we cannot answer. It may be a question that has no real meaning. If you go into a foundry or a forge, you see masses of metal heated to a high temperature. The metal shines and gives forth radiation. If you walk about the streets at night you see light of various colours coming from gases in long glass tubes. The gases are made to shine by means of electrical energy. When you read at night, probably the light comes from filaments of metal enclosed in gas-filled bulbs and heated to a high temperature by electrical energy, or from delicate

"mantles" of metallic oxides heated by burning coal gas. Or you may use the flames of burning gas coming from oil lamps or candles. By day your steps are guided by the light coming from the sun. Everywhere, therefore, we see radiation coming from matter. It looks as though matter were the primeval stuff and radiation a product thereof. The astronomers suggest that in the early state of the universe it was filled with a highly diffuse and tenuous form of matter, which then gravitated together to form, firstly nebulae and then stars like our sun. During these processes matter got hot and began to give forth radiation. But the astronomers cannot tell us at present why the universe in this early state should be filled with a diffuse form of matter, and, if such were indeed the case, what were the still earlier states of the universe. Was the tenuous matter produced from radiation? Leaving these cosmological speculations aside, we find to-day a constant interplay between matter and radiation. Radiation when it falls on matter is partly absorbed, in other words, it partly disappears for a time. The atoms and molecules of the matter become stimulated or energized. Their internal or external kinetic energy may be increased, i.e. they are stimulated in their external or internal motions; or their internal potential energy may be increased. Under certain conditions radiation may produce more drastic results. The absorption of energy may then be sufficient to decompose the molecules or atomic clusters into their constituent atoms, or it may be sufficient to tear out of the atoms one of their essential constitutents, the electrons or units of "negative" electricity. Furthermore, the energized molecules or atoms may be induced to enter into new chemical forms and combinations.

Matter, on the other hand, does not in general give out radiation, i.e. radiant energy, unless it has been stimulated by the previous absorption of energy. Matter at the absolute zero of temperature would give out no radiation. A universe of matter at the absolute zero of temperature would not only be as cold as possible, but as dark as possible. In fact it would be infinitely dark. In order to make an atom or molecule radiate it must have a store of extra energy. This energy may

be derived from another molecule, atom or electron, or from a puff of suitable (i.e. absorbable) radiation. Or the situation may be such that the molecule, either by itself or by the interaction with other molecules, atoms or electrons, can change into other chemical states or combinations of lower potential energy.

A very large part of modern physico-chemical science has been concerned during the last thirty years with an intensive study of this interplay of matter and radiation. It appears to be one of the chief forms of activity in the world as we conceive it to be to-day.

A distinguished physiologist and philosopher has recently contrasted the physico-chemical world of "mechanical chaos" with the beautifully co-ordinated world of biological structure and activity. Such a view seems wholly erroneous. The physico-chemical world as we conceive it to be is anything but chaos. It is still full of co-ordination and organization. There is plenty of organized and co-ordinated energy. Although it may possibly be true that as a *net* result this co-ordinated energy is slowly changing into a state of disorganization, into a more "chaotic" condition, such net secular change is continually being compensated by partial reorganizations or re-co-ordinations. Such a view constitutes indeed the very keynote of modern physico-chemical science. The only real chaos might be a universe devoid of matter and filled only with cold radiant energy in uniform statistical equilibrium. In such a universe there would certainly be no life, no co-ordinated biological structure or activity. Life may be, in fact, only one of the temporary "potentialized" phases in a slowly de-potentializing universe. To maintain that life is the sole organized *potentia* in an otherwise absolutely disorganized and chaotic universe, the only fearless Bayard left to fight against the forces of darkness and disorder, is to do a grave injustice to the fundamental principles which underlie the conceptual world of modern physico-chemical science.

The stimulation of matter to chemical activity by the absorption of radiant energy of a suitable type constitutes, for the student of chemistry, one of the most important and interesting phases of that interplay of matter and radiation

which I have briefly indicated. Photo-chemistry is the name given to this special branch of science. The storing up of potential chemical energy by the green plant in sunlight is a striking example of photo-chemical action. Although this action is not yet fully understood, its great importance justifies some further discussion. As already explained, the radiant energy of visible light is absorbed by the molecules of certain pigments contained in a special organ of the green leaf. Some of the excess energy thus acquired by these molecules is then passed on to neighbouring or combined molecules of carbon dioxide and water, which are thus energized and stimulated to chemical reaction. It is thought that the primary products of this reaction may be a substance known as formaldehyde, and free oxygen. Or the primary product may be a compound of formaldehyde and oxygen, which is subsequently decomposed into its constituents. The formaldehyde molecules thus produced are supposed, on this view, to be immediately condensed together to form sugar and starch. What we actually observe is the formation of starch and free oxygen. Now, suppose we kill the plant while it is still exposed to light and supplied with plenty of carbon dioxide and water. Immediately the formation of starch and oxygen stops. It is evident therefore that the description of the process just given is, to say the least of it, incomplete, for it takes no account of the life process or living structure of the plant. The green plant pigment chlorophyll, if extracted from the plant and brought into solution, will not, when exposed to light, stimulate carbon dioxide and water to react chemically together, though it can stimulate other chemical reactions. It appears that the photo-assimilation of the green leaves is almost certainly not a primary reaction occurring in solution, but a *heterogeneous* reaction in which the molecules of chlorophyll, carbon dioxide and water are held bound to a surface. Other conditions depending on the life process of the plant cells may also be necessary. All we can say with certainty at present is that some of the radiant energy of visible light is absorbed by the chlorophyll and other pigments of the living green leaf, and that some of this energy appears as the potential energy of sugar and oxygen, formed

from the carbon dioxide and water simultaneously present, though these reacting constituents do not themselves directly absorb the radiant energy of visible light.

Another, perhaps simpler, example of photo-chemical action may help us to understand some part at least of the photo-synthetic process in the plant. If we pass an electric discharge through the vapour of mercury, the atoms of the mercury are stimulated or excited by the absorption of energy, and in subsequently giving out this energy they emit a beautiful green light. If we now allow this green light to enter a suitable vessel containing, besides water vapour and oxygen gas, also a little mercury vapour, a substance, hydrogen peroxide, is produced which contains more potential chemical energy than the constituents from which it was formed, namely, water and oxygen. What happens in this case is fairly well understood. The atoms of mercury absorb their own green light, and the energized atoms so produced subsequently pass on some of this excess energy to the molecules of water and oxygen which thus become energized and stimulated to chemical action.

This brief account may help to give us some rough idea of that invisible world in which tiny parcels of energy are being constantly taken up from radiation by the atoms and molecules of matter, which are thus so energized and stimulated that they undergo chemical transformation, or which carry their little cargoes of energy to other atoms and molecules and so stimulate and activate them to chemical action. It is this ceaseless potentialization or organization of energy which makes possible life as we know it to-day. We animals are essentially de-potentializers or disorganizers of an energy that was originally organized for us by the green plants, who are able to store some part of the potential energy of a radiation not in equilibrium with the relatively cool surface of the earth. But is man really only a depotentializer and disorganizer of energy? What are we to say of the shaped clay and hewn stone, of the tall buildings and "dreaming spires" that he leaves behind? Will the cold clay and the solid rocks of the earth do these things themselves? Is a great cathedral but the last vestige of a sunlight long passed

away? No, man leaves some organization of energy behind. But in time earth will claim her own and man's works will crumble into dust.

> "Lo, how the terraced towers, and monstrous round
> Of league-long ramparts rise from out the ground,
> With gardens in the clouds. Then all is gone,
> And Babylon is a memory and a mound."

Why need we complain? We shall have had our day. Our coming and our going will have been splendid phases of a great cosmic evolutionary process and not mere casual events in an incoherent and unrelated universe.

> "What! shall the dateless worlds in dust be blown
> Back to the unremembered and unknown,
> And this frail Thou—This flame of yesterday—
> Burn on, forlorn, immortal, and alone?"

In the preceding discussion I have dealt in the main with phenomena occurring on or near the surface of the earth, phenomena which can be investigated in our scientific laboratories. I have tried to group the facts and theories so far surveyed round the central theme of the sustenance of life on this planet. Now, however, I desire to direct your thoughts to a possible type of activity which has nothing in common with life as we know it here, and which has not yet been, and perhaps never will be, subjected to investigation in our laboratories. We are embarking now on a flight of human imagination than which nothing more daring has ever been attempted. The activity in question represents, or would represent, the most fundamental relation between matter and radiation and also the most fundamental type of chemical action which the human mind has yet conceived. It is a question, in fact, of the possible annihilation and possible birth of matter. One of the difficult problems of astronomy, or of astrophysics (a rather better name for our purpose), is to account for the source of energy of the stars. Our own sun, for example, is reckoned to be thousands of millions of years old. What is the source of the radiant energy which the sun continuously pours forth?

In the past history of astronomy several theories have been advanced to explain this amazing phenomenon, but all have been shown to be inadequate. Some twenty-seven years ago the English astro-physicist, Sir James Jeans, made a daring and fertile suggestion, one of the most brilliant and original that has ever been made. The energy is derived from the annihilation of matter! Matter disappears as such and is transformed into radiant energy. How can such a thing be possible? The surface layer of the sun must have, as previously mentioned, a temperature of about 6,000° C. The temperature of the hottest region of the electric arc may be about 3,000° C. By running electric arcs in gases at high pressure we may expect in our laboratories to attain to temperatures not far removed from that of the sun's surface. We have no reason, however, to suspect that at temperatures of this order of magnitude there is any possibility of the annihilation of matter. The theoretical investigations of modern astronomers, more particularly of Sir James Jeans and Sir Arthur Eddington, have led to the conclusion that the interiors of stars must possess temperatures enormously higher than those corresponding to their general surface radiation. We must reckon the temperatures of stellar interiors in millions, if not in thousands of millions, of degrees. At such gigantic temperatures matter must certainly become "pulverized," i.e. the atoms of matter must be broken up almost entirely into their constituent units, the protons, or at all events the "nuclei," and the electrons. The beginnings of this process can be detected at the temperatures available in our laboratories, so the process itself is no unverified hypothesis. At the very high temperatures of stellar interiors matter will therefore exist in a much simplified state, but it is still matter. For example, it would be still subject to the law of gravitation. Energy has been *required* to break matter up into its simpler constituents. Where then is the source of energy of the star? Let us denote a proton and an electron by the capital letters P and E respectively. The original hypothesis of Jeans may then be represented by the equation,

$$P + E \rightarrow \text{Radiation (radiant energy).}$$

Observe the highly novel character of this equation. It is not an ordinary chemical equation, since there is no matter in the ordinary sense on the right-hand side. It is not an energy equation in the ordinary sense since there is simply matter on the left-hand side. It violates the old principle of the conservation of matter and it appears to violate the principle of the conservation of energy. It is a devastating equation. Now suppose that the action represented by the equation is *reversible*, i.e. that it can go in both directions. We must add another arrow and write the equation as follows:

$$\mathrm{P} + \mathrm{E} \rightleftarrows \text{Radiant Energy.}$$

Read from left to right, this equation says that matter vanishes and is transformed into radiant energy. That is surprising enough to us who are familiar with the law of the conservation of matter, though people two hundred years ago might have had no great difficulty in believing it. But read the equation from right to left and what does it say? Radiant Energy vanishes and is transformed into matter. A creation of matter!

Let us make the assumption that this reversible reaction is possible and try to calculate at what sort of temperature we might expect it to be a common and very frequent occurrence. Let us suppose, with Sir James Jeans, that when a proton and electron collide and disappear, one unit of monochromatic radiant energy is produced. Modern physical theory teaches us that this amount of energy is equal to $h\nu$ ergs, where h is a fundamental constant, known as the Planck unit of action, and ν is the frequency of the monochromatic radiation. Then, using the Einstein equation for the total intrinsic energy corresponding to the proton and electron and assuming that there is conservation of energy, we may write $mc^2 = h\nu$, where m is the mass of the proton plus electron. We know from physical theory that $m = \frac{1}{6 \cdot 06} \times 10^{-23}$ grams, $c = 3 \times 10^{10}$ centimetres per second, and $h = 6 \cdot 5 \times 10^{-27}$ erg-seconds. A simple calculation then gives $\nu = 2 \cdot 2 \times 10^{23}$. This is a tremendous frequency, almost a billion billion times a second. It corresponds to a radiation of wave-length vastly shorter

than the most penetrating X rays (equal, in fact, to $1 \cdot 3 \times 10^{-13}$ centimetre).

In a region of space where the reversible reaction, $P + E \rightleftarrows$ Radiation, is occurring freely, there must be plenty of this extremely high frequency radiation present. In an enclosure at temperature T and in radiation equilibrium, the well-known equation $\lambda T = 0 \cdot 3$ gives the wave-length λ of the radiation of highest energy density. It is therefore plausible to assume that the equation $cT/\nu = 0 \cdot 3$ (since $\lambda = c/\nu$), when we put $\nu = 2 \cdot 2 \times 10^{23}$, will give us the temperature of a region where the reversible reaction $P + E \rightleftarrows$ Radiation would be proceeding freely. A simple calculation shows that $T = 2 \cdot 2 \times 10^{12}$ degrees. This is a terrific temperature, more than a billion degrees. It is possible, however, that such temperatures may exist in the interiors of stars. In such regions our fundamental assumption leads to the conclusion that both the annihilation and the birth of matter would be very frequent occurrences. Professor E. A. Milne, who is renowned for his investigations on stellar phenomena and stellar interiors, has made a very detailed calculation of the reversible chemical equilibrium $P + E \rightleftarrows$ Radiation. I owe to him the following table of preliminary results:

T	n	ρ_P	ρ_R
10^{10}	10^{-202}	$1 \cdot 65 \times 10^{-226}$	$0 \cdot 85 \times 10^{5}$
10^{11}	10^{11}	$1 \cdot 65 \times 10^{-13}$	$0 \cdot 85 \times 10^{9}$
3×10^{11}	$4 \cdot 4 \times 10^{27}$	$7 \cdot 2 \times 10^{3}$	$0 \cdot 69 \times 10^{11}$
10^{12}	$10^{33 \cdot 65}$	$1 \cdot 34 \times 10^{10}$	$0 \cdot 85 \times 10^{13}$
10^{13}	$10^{37 \cdot 3}$	$7 \cdot 7 \times 10^{13}$	$0 \cdot 85 \times 10^{17}$

The first column gives the temperatures in degrees, the second the number of protons present per cubic centimetre, the third the density corresponding to the matter present, in grams per cubic centimetre, whilst the last column gives the density of the radiant energy present, also in grams per cubic centimetre.

It is very interesting to observe from Professor Milne's

figures that the active transformation of radiation into matter becomes appreciable only at about 10^{11} degrees, and that the densities of matter and radiation only become comparable in magnitude at about 10^{12} degrees. Thus the very rough calculation given previously is not in disagreement with the exact results of Professor Milne's theoretical investigation.

At last science has imagined a region where the frequent annihilation and rebirth of matter may possibly be the chief activities present, or at all events very prominent ones. It is a region where radiant energy may be about as dense and as massive as the matter present. To our human minds it is a very terrible region, a veritable pool of glowing fire at a temperature of perhaps a billion degrees. It is something that even Dante, who certainly did not spare the rod to erring spirits, could never have conceived. And yet, what do we find? This terrific radiation in the centre of a star, e.g. the sun, becomes softened in quality as it makes its tortuous way out through the star to the star's surface. Emerging therefrom, it becomes further softened as it penetrates our atmosphere, until at last it shines down on us as the radiance that sustains our life, the precious breath that gave birth to Venus and all her lovely kin. What better example could we have that the universe is one interrelated whole, that the cosmic process is no affair of casual accidents occurring amongst unconnected parts?

A final question remains to be considered. Milne's investigation applies to a space or enclosure where there exists active thermodynamic or statistical equilibrium between matter and radiation. What would or might happen were "hot" radiation of a frequency such as 10^{23} to wander or escape into a cool region of space? Jeans supposes that it would possess the power (limited in amount, of course, by its dilution) of annihilating matter, and would exercise this power should it encounter any. We may ask the converse question, namely, to what extent under such circumstances might this very high frequency radiation be able to produce matter, i.e. protons and electrons? Both events, i.e. the annihilation and the reformation of matter, might be relatively very infrequent occurrences, compared

with the actions occurring in the core of a star at a temperature of 10^{12} degrees. There would, of course, be no question now of thermodynamical equilibrium in the cool region invaded by this high frequency radiation. Actions might occur, however, somewhat analogous to the photo-chemical actions which occur when cool matter is irradiated by high frequency light. Radiation of frequency 10^{23} invading a cool region, and possessing an energy density enormously greater than that corresponding to thermodynamic equilibrium, would certainly possess a high power of transformation into potential or organized energy of another sort.

Such considerations are by no means idle speculations. One of the most important discoveries of modern times is the detection of very high frequency radiations which enter our atmosphere from outer space, the so-called "cosmic" rays. This type of radiation is evidently distributed throughout inter-stellar space. Does it arise from the annihilation or the building up of matter? We enter here one of the most difficult and yet most fascinating regions of modern scientific thought, the problem of the Evolution of the Universe. In the womb of space and time, in the basal metabolism of the universe, does there exist both building up and breaking down?

> "This bowl of milk, the pitch on yonder jar,
> Are strange and far-bound Travellers come from far,
> This is a snow-flake that was once a flame—
> The flame was once the fragment of a star."

Is the visible material universe, as some men think, slowly dissolving into a universe of radiation in eternal equilibrium? Or is the present cosmic process but a passing phase in a universe which oscillates and fluctuates from state to state and in which the word equilibrium has no meaning? No greater problem, no greater question than this, confronts the physico-chemical science of to-day and to-morrow.

ANTHROPOLOGY

by G. ELLIOT SMITH

Anthropology is the study of ourselves. Its subject-matter is the nature of man and human nature. It is concerned not only with the physical qualities of the human body and all that relates to the distinctive attributes of the various races of mankind and their geographical distribution and wanderings, but also with the question of man's ancestry and origin and all the biological facts involved in the endeavour to explain human behaviour and how man's ancestors acquired the qualities which distinguish him from other living creatures. It also aims at understanding and interpreting the customs and beliefs of people in every grade of culture from the primitive nomad to the highly civilized European of the twentieth century.

The study of mankind being the whole-time occupation of all human beings it should be the most advanced department of human knowledge. Nevertheless it is generally admitted to be the most backward. In no branch of learning is there so great a diversity of opinion concerning the fundamental issues involved, or such a lack of discipline in technical methods and arguments. For several centuries philosophers have been trying to explain this paradoxical phenomenon. The real significance of the chaos, however, is fairly obvious. Everyone who embarks upon the study of mankind must first eliminate the ever-present influence of personal bias and acquired prejudice, which is the inevitable result of civilization. It is apt to confuse every issue that arises in the attempt to interpret human thought and behaviour. Every child who is brought up in a modern state acquires from its family and the community at large not only knowledge and the fruits of experience, useful habits and good traditions, but also prejudices and superstitions which influence its thoughts and behaviour and affect its attitude towards other individuals and the interpretation of its own experience. The working of such disturbing factors is further complicated and confused by the personal

feelings of the individual student of anthropology whose experience of life has provided his own prejudices which tend to warp judgment. No attempt to appreciate the present position of anthropology and what the future has in store for the subject can be successful unless due consideration is given to the historical circumstances that have been responsible for the present state of the study of mankind. For it is only a short time since such widespread confusion reigned that it threatened to create utter chaos in every attempt to interpret the thoughts and practices of mankind as they are expressed in beliefs and customs.

That the false doctrines which have held sway for half a century are already doomed, and destined rapidly to disappear, is shown not so much by any frank admission of their error on the part of the disciples of confusion, as by the widespread restlessness on the part of ethnologists, the frequent protests on the part of writers and speakers that they do accept the fact of diffusion. The suppression of references to the writings of those who have unequivocally accepted the reality of diffusion as the true method of interpreting the evidence, does not hide the fact that the truth is prevailing. The admission of the reality of the ancient diffusion of culture is now becoming general. But most ethnologists refuse to recognize that Egypt was the pioneer of civilization, and to admit that the New World was subject to the same influences as shaped the history of the Old.

To the student of biology and comparative psychology the outstanding distinction between men and other living creatures lies in the fact that to the former it is obligatory to acquire the way to live from their fellows. Every human being learns to speak an arbitrary language by hearing and imitating the other human beings in whose society each child is brought up. Moreover, it is not merely a language that the child learns, but incidentally he also acquires some part of an organized system of ideas and beliefs, methods of behaviour and a composite culture that are distinctive of the society in which the individual lives and moves. No individual acquires the whole cultural heritage of his society, nor does he adopt those parts of the

culture which he assimilates in a completely stereotyped form. The ability and the fortuitous circumstances of the personal experiences of each individual determine how much and in what form the available customs and beliefs are adopted and shaped in the process of assimilation. Every individual who accepts the, so to speak, raw material of any culture, inevitably rationalizes such knowledge and experience and adapts it to his own peculiar circumstances. This, however, does not affect the principle that the fundamental distinction of human behaviour is the diffusion of culture, the reliance of each individual on his fellows for information and beliefs, and the handing of them on in some more or less altered form to other human beings. As the result of this process there is a link between different human communities in space and time. There is a spreading, more or less wide, from each particular centre of the influence of the culture it has gained, and there is also the process of transmission from one generation to another of the accumulated knowledge which any community possesses. Obvious as these facts are and familiar as every human being is with their reality, it is unfortunately necessary at the present moment to emphasize them because anthropologists—the very people who set up to study and interpret the nature of man and of human behaviour—repeatedly ignore and sometimes even definitely deny them. In the great majority of cases many modern ethnologists seriously minimize their influence. Until anthropologists can get rid of their obsessions against the idea of diffusion and the addiction to shibboleths which prevent them from seeing the patent facts of human behaviour, and frankly and honestly admit what they see, anthropology will not extricate itself from the tangle in which it is at present involved. But as I have already said, there are definite indications that the truth is beginning to prevail, if the first signs of enlightenment are obviously disturbing to the people who are affected.

It will be a great step forward when ethnologists learn the true meaning of the word evolution, and appreciate the revolution effected in behaviour by the emergence of the human mind.

The Biological Aspect of the Study of Man

Events of the last three years have done much to shed a new illumination upon the early history of the human family and provide a new confidence in the validity of our inferences. The discovery of the remains of early Pleistocene Man at Chou Kou Tien, near Peking, has revealed to us what is probably the most primitive and generalized type of human being which has yet been recovered, and under circumstances that precisely determine the geological age. The association of the Peking Man with early Pleistocene fossils is free from the doubts which still exist in the case of *Pithecanthropus* and *Eoanthropus*—the fossil Ape Man of Java and the Dawn Man of Piltdown respectively. Moreover, the primitive human being whose remains were found in China reveals associated in one and the same skull peculiar features, some of which were hitherto unknown except in the case of *Pithecanthropus*, and others only in the Piltdown skull. Hence the Man of Peking forms a bond of union between these two primitive genera which hitherto were thought to be irreconcilable one with the other. The discoveries in China have given a cohesion to our knowledge of primitive man which hitherto has been lacking, and have established a definite geological age of the most generalized of the three early types. Thus they give us a precise idea of the nature of the earliest members of the human family, and enable us to form some idea of what the common ancestor of these three genera, the still hypothetical Pliocene Man, must have been like.

As to the actual age in figures of these earliest men and the geographical situation of the cradle of the human family, there is still uncertainty. To take the question of age first, I cannot do better than quote a concise statement made in 1928 by the late Professor W. D. Matthew, F.R.S.:

"There is a method of calculating the age of rocks which seems to be independent of the varying rates of geologic processes, and is not based upon any hypothesis of the origin of the earth, but upon the *rate of alteration of the radio-active elements*. The element uranium is gradually changing through

a series of intermediates, of which radium is one, and lead is one of the final products. Uranium minerals as we find them in the rock are always accompanied by a varying proportion of lead minerals. That is to say, wherever you find pitchblende there is always some galena with it, and the older the rock is geologically the more galena relatively to the pitchblende. Now the rate of this change is apparently always the same. Heat or cold, dryness or solution, different chemical combinations or conditions make no difference to it; it goes on at a fixed definite rate, and this rate can be measured in a laboratory. Moreover it is possible to distinguish the lead that results from the decay of uranium from the lead from the other sources that might be accidentally associated, by a slight difference in its atomic weight.

"Now the pitchblende occurs in veins in various formations. The time at which those veins were made and filled with pitchblende must be later than the rock around it—how much later the geologist can determine by the relations of the vein to subsequent formations. The pitchblende was crystallized from solution and free from galena at the time it was deposited there. The amount of galena that has been formed from it since is a measure of the age of the vein; the country rock is, of course, older.

"Here, then, we seem to have a way of getting at the real length of geologic time. It is too new to have been as fully tested as one could wish, and there are certain discrepancies and criticisms that I will not discuss here. But it is widely accepted now as being a sound and reliable method. It gives results much higher than the older methods; but that was to be expected in view of the fact that, as pointed out above, the old calculations were probably far below the true age. The total length of time to the oldest rocks figures at between fourteen and fifteen hundred million years. Of this time about one-half is before the Cambrian period when the life record begins. Our life record covers, then, between seven and eight hundred million years. The Tertiary period or Age of Mammals is estimated at between fifty and sixty million years, while the Age of Man may cover a million years."

As long ago as 1899, Professor Joly in Dublin, followed in 1908 by Professor Boltwood of Yale University, and others, suggested the use of radioactive changes in rocks as a geological chronometer. Holmes and Lawson (1927), Kovarik (1930), and von Hevesy (1930) have measured the natural disintegration of uranium into lead in the oldest igneous rocks containing radio-active elements and arrived at an estimate of 1,852,000,000 years. Using the time scale which geologists have gradually determined since William Smith in 1796 made the first estimate, there is little room for doubt that the end of the Pliocene can be referred to a time which is approximately one two-thousandth of the whole scale—in other words, roughly a million years ago. Recent researches on this problem have been clearly summarized by Dr. Chester A. Reeds in an article entitled "How Old is the Earth?" in *Natural History* (March–April 1931). Assuming the reality of Pliocene Man, Dr. Reeds suggests that the antiquity of man must be at least 1,500,000 years.

The Cradle of the Human Family

In attempting to determine the site of the birthplace of mankind, due consideration must be given to the early wanderings of apes and men and the light such evidence sheds on the problems, not merely of the birthplace of the human family, but also of the influence of change in environment in provoking in apes such profound changes as eventually led to the emergence of the qualities distinctive of man.

So long ago as 1863, Sir Charles Lyell (in the third edition of his *Antiquity of Man*) discussed the possibility that in Equatorial Africa or the Malay Archipelago there might be discovered fossil remains of apes more closely resembling man than do any of the apes now living in these regions. In the first edition of his *Descent of Man*, Charles Darwin in 1871 suggested that, as the Gorilla and Chimpanzee were structurally more nearly akin to man than the Orang-Utan and Gibbon, Africa rather than Indonesia was more likely to provide the missing links in the chain of man's ancestry. In 1886 Alfred

Russell Wallace (*The Malay Archipelago*) threw out the hint that the caves and Tertiary deposits of tropical lands might provide interesting evidence to settle this problem. In the same year Julien Fraipont's description of the skeleton of Neanderthal type found at Spy in Belgium seemed to suggest that the West was not likely to reveal relevant fossils which were not definitely and unmistakably human. Hence Eugene Dubois thought it worth while to take the hint provided by the discoveries of fossil apes in the Sivalik Hills of India, and in Java (in 1886) of mammalian fossils similar to those found along with the Sivalik apes, and examine the caves of Sumatra and the Pliocene and Pleistocene deposits of Java. In 1891 the adventure prompted by this romantic speculation led to the discovery of *Pithecanthropus* on the banks of the Solo River in Central Java and aroused a new interest in the Far East as the possible cradle of the human family.

The balance of evidence in favour of the West—or rather in neutralization of the not altogether relevant inferences from the discovery in Java—was restored in 1912 by the finding of equally ancient but much more highly developed human remains at Piltdown in Sussex. The recent discoveries (1927–1930) near Peking have been claimed as evidence for swinging the balance back again to the East, and as a justification of the predictions of the anthropologists who were searching for early man in China.

The finding of remains of Early Pleistocene man in regions as far apart as Java, England, and China surely establishes the fact that men had already roamed throughout the whole length and breadth of the genial part of the great Continental land mass of the Old World. Hence no one of these widely scattered remains of three distinct genera necessarily throws any light upon the place where the much more ancient common ancestor of all three came into being and lived before the world-wide wanderings of his descendants.

If the geographical evidence sheds no decisive light upon these problems we are still free to speculate on the relative possibility of Darwin's argument for Africa as the home, and the considerations submitted by many writers in favour of

Asia, which have recently been set forth and critically examined by Professor Grabau of Peking.

Assuming that some catastrophic change of environment and profound alterations in the conditions of life were essential to compel a primitive ape to adapt himself to new circumstances, and in the process of overcoming such difficulties to become human, Grabau accepts the old hypothesis put forward many years previously by the late Professor Joseph Barrell of Yale University that the raising up of the Himalayas at the beginning of the Miocene separated the anthropoid apes into two groups. One of them remained in India and continued to enjoy the old method of life in tropical forests and therefore had no incentive to change; the other, thrown into new conditions of climate and environment north of the great mountain barrier, perhaps in the Sinkiang province of Chinese Turkestan, only saved itself from extinction by adapting its structure and mode of life to the new circumstances and so became transformed to attain human rank. Although this interesting speculation seems to fit most of the facts at present known, it is important to recognize that it is only a hypothesis as yet unsupported by any decisive evidence.

The Miocene or Pliocene ape which acquired the higher powers of understanding and skill distinctive of human rank may have taken the first step to achieve this momentous change in the world's history somewhere in Western Asia or the neighbouring part of Africa, but where the making of man was achieved is a question that cannot be answered until Turkestan, Southern Asia, or Tropical Africa yields up its secret.

Two considerations, however, still dominate the issue. The living apes, Gorilla and Chimpanzee, that display signs of the closest kinship to man occupy the heart of Africa. The much more primitive extinct apes (*Dryopithecus*, *Australopithecus*, and *Sivapithecus*) revealing tokens of an even closer human affinity have been recovered from Europe, South Africa, and the Sivaliks in India. For these reasons, it seems more probable than not that the pilgrimage which led to the emergence of the human family extended from India towards the West.

Hence the claims of Africa as the possible cradle of mankind cannot be overlooked.

Cultural Anthropology

Much of the confusion and the widespread lack of discipline that is conspicuous in anthropology to-day, hampering clear thinking and progress in interpretation, are due to the neglect to give due consideration to the distinctive attributes of mankind, the qualities which differentiate man from all other living creatures. In formulating speculations based upon an assumed evolution of culture it is the common practice to neglect the distinctively human qualities of mankind, the very factors that enable man to do what no other creature can do, namely create culture and devise a system of civilization.

The behaviour of other animals is determined by impulses which the physical structure and the physiological activities of their bodies determine to satisfy their own needs and feelings in relation to the changing circumstances in the world. Imitation of the actions of their parents and other members of their family group represents a kind of education, which enables many animals such as mammals and birds in some slight measure to profit from the experience of their community.

In the case of human beings this dependence on others for a knowledge of the way to live is enormously enhanced, so that it is the dominant influence in behaviour. The brain of man is an instrument for enabling its possessor to accumulate knowledge and to give expression to it in biologically useful actions displaying high degrees of muscular skill, which each individual is irresistibly impelled to acquire. Enormously as man's understanding and skill transcend those of other creatures, however, his distinctive attribute is the ability by means of articulate speech and gesture to share his knowledge and his superstitions with others, and to hand on such varieties of experience from one generation to another. Hence the most distinctive achievement of mankind is the accumulation of the fruits of experience. As the result, every human child

finds ready-made for him a vast instrument of stereotyped ways of thought and action, which he has to learn to use. Highly equipped as he is with discriminative instruments of sight, touch, and hearing to learn from direct observation of the world around him, and with the aptitude to display his skill in useful actions, as a matter of fact his reliance upon direct observation and original behaviour is infinitesimal in comparison with the accumulated experience and knowledge of the community in which he grows up. As Mr. Arnold Toynbee, from whose book, *A Journey to China*, I have taken some of these phrases, expresses the issue: "The sum of this knowledge is at the individual's disposal only at second-hand. . . . In order to live at all he must be working all the time upon provisional representations of the universe which he has put together from other people's reports." Every child is brought up in an atmosphere of tradition, an arbitrary mixture of sound experience and false superstition, the precise blending of which in any community can be interpreted only by studying the history of the process by which the various customs and beliefs were acquired and adapted to the special circumstances of a particular people. To have what the late Dr. Rivers called a functional value elements of culture that have been handed on from one generation to another must be given a purpose, a biological usefulness, adapted to the special circumstances in the daily life of the people amongst whom they survive. Hence a process of re-adaptation is constantly in operation, often, however, so slight and subtle that practices which once served some vital purpose may survive with little change long after they have lost their real function, and even when it is entirely forgotten by the people who continue to observe the sterile tradition.

Hence it becomes essential for any individual who, having grown up in the atmosphere of stereotyped tradition, wants really to see the true light from time to time "to confront his imagination with the reality of life." The greatest achievement of the age in which we are living is the growing dominance of the discipline of science—the increasing ability to set aside traditional superstitions and actually observe and experiment.

We live in an age of invention and are in large measure immune from the dangers to which men of inventive mind were exposed in former generations. Yet it is not generally recognized how vastly complex and intricate is the process of invention, how much it is dependent upon the work of former generations, how large a part accident plays in producing at the psychological moment the man with the knowledge and the appreciation of the need to apply a certain idea when the appropriate circumstances arise, as well as the courage and persistence to defy the jeers of his more stupid and obstinate fellows in securing the adoption of his innovation.

The familiar stories of the invention of the steam-engine as the outcome of two thousand years of experiment and the discovery of the usefulness of electricity after centuries of apparently futile speculation serve to give point to the issues I have raised.

No significant invention, even of the simplest device, was ever made except as the outcome of a large series of more or less accidental happenings. Eventually a man of insight and courage realized the possibility of doing the thing and was not afraid to bear the obloquy which as a rule is involved when tradition is defied and an innovation introduced. It is only when the complexity of the process of invention is appreciated that one feels the full force of scepticism as to the possibility of any two groups of men, however similar their needs and however great their abilities, making a similar invention in complete isolation and independence one of another. Hence it would require complete evidence of absence of contact, direct or indirect, to convince the impartial student that similar inventions were really made independently. No such case of independent invention has ever been recorded. In the case of every invention of which we have a full record it is clear that a complicated chain of events may link up achievements in widely distant countries and centuries to explain even so simple an instrument as a steam-driven machine or a clock to measure time. Every ingredient of civilization of which the history is known or inferred from internal evidence was brought into functional use at one spot and from there carried by

travellers to other places until in many cases the chain of secondary diffusions of culture encircled the whole world.

In attempting to interpret the problems of anthropology it is in the first place essential not to forget man's most outstanding distinction, the ability and the necessity of learning from other men and the subjection to the influence of tradition. The principle of continuity and the diffusion of culture are the vital factors involved. The understanding and interpretation of human nature and human behaviour can be attained only by the historical method, studying the thoughts and actions of men to-day in the light of the historical circumstances which led up to our present problems.

If it took man more than a million years to discover that, instead of spending all his time and energies in the search for food, he could grow corn and breed cattle, is it likely that such an event happened more than once? The evidence that is available suggests that the people in one locality invented agriculture long before any other people abandoned the primitive nomadic life and that the cultivation of barley and wheat, or of rice, *taro*, or maize in more and more distant places was due to introduction in these several places of the mere idea as well as the methods of agriculture originally devised for growing barley. That this actually happened in Egypt long before 3500 B.C. is established by complete evidence, which I have already summarized in the words of Professor Thomas Cherry in my book *Human History*. Egypt alone provided the peculiar geographical and biological circumstances which made the discovery possible. It has been objected by certain critics that the evidence on which the argument was based—the finding of barley in the stomachs of the early Predynastic Egyptians excavated at Naga-ed-Dêr by the Phoebe Hearst Expedition in 1901—is not valid because neither Professor George A. Reisner nor Mr. Albert M. Lythgoe, who were responsible for the excavations, has yet published the descriptions of the individual graves. Are we then to discredit the conclusions of the most competent and conscientious archaeologists who have ever worked in Egypt? Fortunately, this criticism does not affect their reliability, because

the very writers who refuse to accept the evidence from Naga-ed-Dêr themselves admit the validity of the so-called Badarian culture in Egypt and assign to it (and the use of cereals which forms part of it) an age as remote or even more remote than the Early Predynastic.

Being thus committed to a vastly more ancient date for the practice of agriculture in Egypt than elsewhere, my critics still refuse to admit that it was invented in Egypt. Neither evidence nor argument is adduced to justify the claims that are put forward in favour of Sumer, Syria, or any place that is not Egypt, until the conclusion is forced upon one's mind that some emotional factor must be obscuring the clear light of reason. No good apparently can come out of Egypt! One is tempted to inquire whether the persistence of the bias inculcated in early childhood that the Egyptians were depicted as bad men who oppressed the chosen of God is responsible for the persistent denial of the fact. In no other way can I explain the obstinate refusal to accept the clear evidence of the origin of agriculture and civilization and its obvious significance. It is futile to pretend that contemptuous references to "Pan-Egyptian theories" can invalidate the patent meaning of the evidence.

The history of the invention and development of sea-going ships establishes beyond all reasonable doubt that the chief instruments whereby the diffusion of culture was effected are Egyptian. The survival of ships of ancient types in the Mediterranean and Indian oceans, the lakes and rivers of East Africa, India, Burma, Indo-China, and the Malay Archipelago, as well as the coasts in Oceania and America, affords the most conclusive testimony of the reality of the maritime trafficking such ships were intended to make possible. Such far-flung voyages necessarily involved the diffusion of culture. In addition, the evidence points definitely to Egypt not merely as the cradle of ship-building, and of the craftsmanship of the sailor, but also as the starting-place of diffusion. The same result emerges from the intensive study of the origin of metal-working and the use of metal tools, the working of wood and stone, the invention of stone buildings, the making of statues, the creation

of architecture and of architectural designs. Egypt has preserved not only the earliest buildings made of stone and the most ancient rock-cut chambers, but also the evidence of the reasons responsible for this great step forward in the history of civilization. Equally clear is the evidence provided by Egypt for the invention of the copper chisel which made stone-working and carpentry possible.

Egypt was the original home not only of agriculture, ship-building, architecture, metal-working, and wood-carving, but also of such political institutions as the kingship and the custom of calling the ruler the Son of the Sun, the practice of mummifying the king and regarding his body and his existence as enduring after death. The measures adopted in childlike faith for restoring life to the king's mummy by the ceremonies of opening the mouth, incense-burning, and making libations, dancing, singing, fighting, and play-acting were all Egyptian inventions, out of which developed not only the ritual of every religion, but also the drama, dancing, music, and games of modern peoples throughout the world.

No one denies that the Egyptians invented writing and gave us our own alphabet, pens and paper.

One might go on citing one after another of the political, social, religious, economic, industrial, and other ingredients of early civilizations, in respect of which the origin can be traced back to Egypt. Why did it happen that Egypt was the pioneer in the invention of all the essential practices of civilization? It was not due to any superiority in intellectual equipment or to the consideration that other peoples were not equally competent to do these things. The fact that for countless thousands of years people who were constantly searching for food and security did none of these things ought to convince us that there is no innate impulse in mankind to devise all the varied arts and crafts and the social and political organizations which go to the making of civilization.

It was a peculiar set of circumstances which impelled the Egyptians to invent agriculture. All the rest followed in the train of this momentous event in human history. For the introduction of the practice of tilling the soil on the banks of

the Nile involved the creation of civilization. It compelled men to study the phenomena of the inundation, to measure the year, to order their lives so as to know when to plant their barley, to store the grain not only for food, but for planting, to build granaries for the seed and houses for themselves, to organize the community so that all men might share in the just distribution of the water of irrigation, to settle in villages and to make cemeteries. With the increased leisure afforded by this agricultural mode of life in which to the assured supply of food from the cereal crop was added the abundance of animal food, not merely from increased facilities for fishing and hunting, but also from the domestication of cattle and geese, which first became possible under the circumstances of the settled mode of life of the farmer. It was more or less accidental that the first people to enjoy the leisure of this more secure life should have discovered the use of gold and copper and have invented tools of metal which enabled them to devise the crafts of the carpenter and the stonemason. These were first used for securing better protection for the dead in the hope and belief that preservation of their bodies would secure a continuation of their existence, but afterwards they were applied for the benefit of the living. Civilization is a highly organized mode of existence which was not created piecemeal, but as a complete system of intimately interwoven customs and practices.

The earliest people to live in villages under the leadership of a man who studied the river and the sky, measured the year, and controlled the distribution of water, had many novel problems of vital interest and importance to occupy their thoughts and speculations. How did water stir into life the apparently dead grain? What caused the inundation of the life-giving waters of the river? What was the explanation of the coincidence between certain celestial phenomena and the rising of the Nile? How was the king able to predict the time of the inundation? Was he himself able to cause the river to rise, and after a time to fall again to produce the dry land? Was he in fact the creator of the dry land and the controller of the river? Was it he who conferred the life-giving powers to the

water and gave life to barley and men? Did he also control the heavens which seemed to have some influence over mundane events? Out of some such speculations as these there gradually emerged the conception of a king who was the creator of his subjects and the earth, who conferred life on crops and mankind, and who regulated the universe which he had made. The influence of this conception of an irrigation-engineer, who became a king and eventually a god, shaped the whole organization of the primitive state and its political and religious systems.

Out of the desire to obtain security civilization was born. The constant preoccupation with measures for the safeguarding of life inspired far-reaching speculations concerning the properties of a variety of objects and magical devices to protect life and avert danger. No circumstance on the earth or in the heavens which seemed to influence the life-giving powers in river, cornfield, or human beings was omitted from these speculations. Hence there rapidly developed a complex system of doctrines which found expression in ritual and what we would now call magic, as to the factors controlling human destiny. So strong is man's craving for safety and resentment of the idea of extinction that many of these early beliefs have survived throughout sixty centuries. Whether we label them religion or superstition, ritual or magic, they still affect the thoughts and actions of the vast majority of human beings to-day.

Egypt invented agriculture and this involved the making of civilization with all its essential practices. This happened centuries before any other people had abandoned the cultureless nomadic life. Immigrants from Egypt prospecting in foreign lands for materials, for which in many cases their own inventions had created a value, introduced the new practices into Crete, Syria, and Mesopotamia. It was not until several centuries later that Mesopotamia handed on its culture to Northern India and the heart of Asia, while Egypt and East Africa were busy planting colonies on the gold-and-pearl-producing lands of Southern India. Thence the effects were carried respectively to China and Indo-China, to Indonesia, Oceania, and finally

to America. From Egypt an influence was gradually being diffused through Africa, without, however, stimulating any such profoundly significant results as she was able to promote in the non-negroid peoples of Asia and America. From Egypt, Crete, and Anatolia, Europe derived her culture.

Since this scheme of cultural diffusion was first tentatively propounded in 1911, the attitude of anthropologists has undergone a profound change. Although few of them accept it in its entirety most anthropologists are now "diffusionists." It is true most of them want to bring culture from some place other than Egypt—such as Sumer or Elam, Syria or Northern Europe, India or China—but their theories assume that diffusion of culture did actually occur in ancient times. Even the American anthropologists, while still subscribing with quasi-religious fervour to their Ethnological Monro doctrine—that no outside influence can be recognized in the origin and development of Pre-Columbian American civilization—freely admit the diffusion of culture within the Americas. Although they no longer deny the fact that the original colonists into America came from the Old World they refuse to admit that later and more cultured people could possibly have done what the uncultured earlier people did, that is, make their way into America. If there is any truth in the essential doctrine expounded in this lecture that when man's million-year-old lethargy was brought to an end as the result of a fortuitous set of circumstances in one place, whence the influence gradually spread to the rest of the world, it becomes impossible to exclude America from the operation of the universal principle. When, however, we find in the New World the earliest signs of civilization near the Pacific littoral, and reproducing the peculiarly distinctive traits of the culture flourishing in the same centuries on the other side of the Pacific—in Annam, Cambodia, Java, and elsewhere in Eastern Asia—it becomes impossible to deny that America derived its original cultural capital from the Old World, perhaps no earlier than six centuries before Columbus opened the way for Europe to inaugurate a new phase of influence of the Old World in the New.

The Expression of Man's Aesthetic Aptitude

It is commonly assumed by students of anthropology that the ability to do a particular thing will almost inevitably result in this thing being done and done quite independently of any suggestion from other men. Before the Neolithic Epoch men made no attempt to make polished stone implements, although it is not denied that they were endowed with the human qualities of vision and skill which conferred upon them the aptitude to do such things. From the earliest times when human beings discovered that they could make useful implements of stone they also displayed in the symmetry of form and the graceful contours of their artefacts the possession of a keen aesthetic sense. But it was not until relatively recent times, a mere fifty centuries ago, that they attempted to achieve the task of portrait-making or statuary.

Several years ago at Saqqara (Lower Egypt) a life-size statue of King Zoser was found in position in the room built against the north side of the Step Pyramid. Its discoverer, Mr. Cecil Firth, says it is the oldest royal statue of life size yet found. A statuette of King Khasekhemui of the second dynasty is perhaps the only known earlier portrait. For centuries before life-sized statues were made, however, sculptors had shown that their absence was not due to any lack of the ability to model the human figure. Such life-size portraits were not made, simply because the special circumstances had not yet arisen to prompt sculptors to make statues of such proportions. The incentive to do so arose from the demand for the preservation of the form of the living body as an essential condition for the attainment of survival after death. The making of a life-like image was considered to be tantamount to the prolongation of the model's existence and life. But such beliefs were not the invention of a moment. They only emerged after centuries of striving to avert the fate of annihilation at death.

The practice of mummifying the dead was invented in Egypt in the belief that the preservation of the body implied the prolongation of existence. For this purpose it was considered necessary, however, not merely to render the body incor-

ruptible but also to maintain its outward form and life-like appearance. The dead man's individuality and appearance as he was when alive were believed to endure if his corpse could be converted into a durable statue to preserve his likeness.

When the embalmers realized their inability to attain the latter aim—as early as the second Egyptian dynasty—they adopted the device of swathing the mummified body in bandages and so trying to build it up into the likeness of the individual, the features being indicated by paint upon the wrappings. Then they adopted the procedure of applying resinous paste, plaster, or mud to the face of the wrapped mummy and moulding these plastic materials to represent the dead man's features.

After many varied experiments of this kind the conviction seems to have been impressed upon the embalmer of the inadequacy of all such procedures to attain the desired result—that is, of converting either the mummy itself or the wrapping that swathed it into a satisfactory likeness of the deceased. Hence sculptors were impelled to try, altogether apart from the body, to make life-size portrait statues in stone or wood to preserve the living image. For when the statue (at first of the head alone, or later of the whole body) was modelled, it was painted and artificial eyes were inserted so as to make it not only an accurate portrait, but to make it alive and so ensure the prolongation of the model's existence as an animate being.

This practical purpose was the primary (and in fact sole) aim of the earliest makers of life-size portrait statues. It was not an art so much as a craft and a ritual—a meticulously exact copying of the traits of a living person with the essentially religious object of conferring, if not immortality, at any rate a prolongation of existence after death.

The early Greek writers attributed the invention of sculpture to Daedalus, asserting that he made his statues so life-like that they could even see and speak.

In this Greek tradition survives a faithful account of the real motives which inspired the original inventors of portrait statuary in Egypt. The aim of the sculptor was to create a

model that was so life-like as to make the tokens of life permanent. The statue was regarded as "a living image," not merely in the symbolic sense of the words but actually.

At first the feeling for beauty does not seem to have consciously entered into the sculptor's motives. For he did not hesitate to disfigure the most beautiful materials, alabaster, diorite, or wood, by painting them to give the life-like colours to the model. In spite of these handicaps some of the earliest sculptors were such superb craftsmen and so intent upon their simple and truthful workmanship that they did achieve work of real artistic merit.

In the pursuit of this essentially practical aim of making images that would live the craftsman must soon have come to realize what modern writers call the "magic" of his skill, and, like Pygmalion, have fallen under the spell of the beauty he had created. Then he became something more than a mere craftsman: the realization of the aesthetic qualities of the Galatea fashioned by his own hands transformed him into an artist, the man who strives to express his sympathies and feeling for beauty with chisel and brush.

Art was created, so to speak, unintentionally: it was not primarily invented as an expression of man's feeling for beauty but to serve certain definite practical purposes. But out of the experience gained in such practices the opportunities immediately arose for the display of the emotional and aesthetic qualities which are innate in man. To express the matter in another way: man probably did not appreciate the beauties of the world in which he lived or his own aptitude for the creation of beautiful things until certain events forced him to study them and endeavour to represent them. Out of such striving art was born. Art in turn educated man to appreciate beauty.

This sketch of the origin of sculpture is typical of all progress in the arts and crafts of civilization—the accidental circumstances which lead men to attempt to achieve some concrete aim enabled them in doing it to appreciate their own powers and feelings.

Human Nature

Looking into the future and trying to envisage the fate of civilization, the most decisive influence must be the true understanding of human nature. Only when the springs of human thought and action are justly appreciated can social and political policy be so shaped as to secure peace and prosperity by eliminating causes of friction and conflict.

It is of fundamental importance to recognize the fact, which should be patent to everyone from daily experience of intercourse with other human beings, that the actions of most people are decent and generous. It is the rare exception rather than the rule to meet with malice and cruelty. When this does happen there is usually some definite reason, jealousy or the sense of insult, real or imaginary, something that seems to imperil the welfare or the personal status of the individual who resents the insult by an unnatural display of inhumanity. It is misleading to assume that pugnacity—what Mr. Stanley Baldwin calls "the instinct of the tiger"—is "an innate characteristic of human nature." Obviously man has an instinct of pugnacity, but it is called forth only by the feeling of resentment at some action which imperils the safety or the *amour-propre* of the individual. The practical importance of this fine distinction is tremendous. For if it be recognized that man's innate tendency is to act decently and generously towards others, and that cruelty and injustice are departures from the natural mode of behaviour, the possibility of avoiding such incentives to unsocial conduct gives reality to the hope that peace is definitely attainable. There is a widespread belief that war is the way of progress, that people endowed with superior qualities of valour and intelligence can attain proper expression for their merits only by fighting and destroying the craven and dull-witted. Though this crazy misapplication of the biological phrase, "survival of the fittest," belongs essentially to the past of Treitsche and Bernhardi it is not wholly dead. No sane man or woman can fail to recognize that warfare does bring out the great qualities of courage and self-sacrifice. The men who fight their country's battles are called upon to display

the heroic virtues of unselfishness and renunciation on the altar of patriotism and loyalty, and deserve every distinction a grateful nation can confer in recognition of their service and devotion. While frankly admitting that such conflicts may bring increased power to peoples more highly endowed with courage and insight, this should not blind us to the fact that war is not the way of progress. War, like disease, may evoke the display of the highest human qualities of courage and renunciation, but it is essentially destructive and degrading. So far from promoting progress it causes widespread interference with the expression of those qualities which we significantly call humane. It has been assumed by some students of mankind, the class one might distinguish as the courageous talkers, that as the virile peoples who have attained success by warfare in many cases enjoy more powerful influence than their less belligerent neighbours, war is the way of progress and strength.

If the study of mankind can destroy the fallacy that war is essential for progress, it will help the great movement of enlightenment now stirring which aims at eliminating from the policy of the nations a device so destructive and wasteful as organized conflict.

The rational investigation of human nature should enable us the better to understand peoples of different origin and traditions and sympathetically to enter into their feelings and appreciate their aspirations. It is hardly necessary to emphasize how much the attitude of anthropology in the future can contribute to the promotion of the welfare of mankind.

MEDICINE, ITS PRESENT DEVELOPMENT AND POSSIBILITIES

by DR. JANE WALKER, C.H., J.P., LL.D., etc.

IN looking over the Syllabus of Morley College, amongst the items of General Information for Students, I find that under the heading *Objects*, 1st, is given, "To promote the advanced study by working men and women of subjects not *directly* connected with or applied to any handicraft or trade or business."

Now I take that to mean that Morley College exists, and rightly exists, not so much to help people to gain their own livelihood strictly by helping them to improve themselves to that end, but to enable them by taking a really broader view of life to carry on their work with more real enjoyment and intelligence. From this it naturally follows, I think, that this series of lectures is pre-eminently conducive to that end. **Science—that is, knowledge, general as well as special—to-day and to-morrow.** In other words, we are looking forward and not backward—which is one of the most hopeful characteristics of the age in which we are living. Oh yes, people may say, but you must have a background. That is very true, and only proves my contention; for a background is not the main or chief thing at which you look, but it merely exists to throw up into clearer, truer light what there is in front.

This is specially true of my particular section of Medicine. When a patient consults a doctor, what he wants to know first and foremost is, what is going to happen to him, is he going to get well, will he have to give up his work, and so forth. It is true that to enable these points to be answered, intelligent inquiries into his past history as well as observations as to his present condition must both have their share in determining the outlook, or, as we say, in giving a true Prognosis as to the future. All this is very difficult, and needs the widest and most intelligent experience.

In speaking about Medicine, it must never be forgotten that it is an Art and not in the strict sense of the word a Science at all. It is the Art of Healing, and it never can be an exact Science because human nature is not exact—it does not react to certain rules, and the wider and more extensive the knowledge the more clearly that comes out. People are inclined to think that because many wonderful inventions are in use nowadays, such as X-rays, Ultra-violet Rays, Electro Cardiagraphs for examining the heart, that Medicine has become more scientific. I very much doubt if that is the case. All these things are excellent servants in the strict sense of the term, i.e. to whom orders may be given by an intelligent mind behind, but they are downright bad masters not infrequently leading to quite wrong conclusions.

But there is another side to Medicine as a Healing Art, and that is Preventive Medicine, and it is this aspect of the subject that more fairly falls under our consideration in this lecture, for it is the undoubted trend of modern policy and action. "If preventible, why not prevented," was the pertinent question asked by King Edward VII, when Prince of Wales, at the Marlborough House meeting in the autumn of 1898, when the great campaign against tuberculosis was fairly launched. I think it may fairly be contended that ever since that time all public effort has been in the direction of prevention of disease, though in common with all human endeavour it may partially fail in its object. . . . It is one of the great paradoxes of the medical profession that it tries to stop the very thing by which it makes its living, and the more successful it is in its efforts the more pleased it is. There can be no medical practitioner living who regrets the passing of typhus, and now in these later days of typhoid fever too, and yet they were a considerable source of income when they were rife in epidemic form.

Speaking generally, I am quite sure that we are living in an age when prevention rather than cure of disease is the ideal, and that this view will obtain more and more as time goes on. But hopeful as is the outlook, the present position still leaves a great deal to be desired. Medical students, for example, are

not taught anything about the prevention of disease and uncommonly little about the early beginnings. Practically no hospital takes slight cases of illness into its wards, and so the newly fledged medical practitioner finds himself or herself in the unenviable position of being unable to treat the bulk of the small trifling ailments that rightly form a large proportion of the ordinary general practitioner's work. It is indeed only too common a saying with them that they have to unlearn a large part of what was taught them as students to enable them to gain the qualification which gives them the right and privilege of dealing with the physical and mental ills, not to say moral ones, that affect the people who call for their assistance. In the case of midwifery, for example, the actual practical knowledge necessary for most medical students to pass their examination in that subject is very small indeed. I am informed on very good authority that in one well-known London hospital the number of confinements which must be *seen* to qualify a student for his examination is four. This compares very badly with the number necessary for a midwife to obtain the certificate of the Central Midwives Board.

Then few medical students have ever seen an early case of tubercular disease of the lungs. A few attend the Tuberculosis Dispensary which is in some cases attached to their hospital. No cases of tuberculosis are allowed in the general wards of a hospital, and in those wards where they are taken the cases are such that it hardly needs any medical learning to recognize them. Then surgery, which is so attractive to the young student—it is so very dramatic—is no real help at all in the prevention of disease. The saving of life that has resulted from surgery is undoubted, and the advances in that direction are most striking and obvious and undeniable. But as James Mackenzie points out in his illuminating book, *The Future of Medicine*, "the Surgeon only comes in at a stage of disease when it has advanced so far as to have damaged tissue and grossly perverted function. He might be said to flourish on the failure of the physician—in the sense that the early and curable stages have been overlooked or unsuccessfully combated."

Even in surgery there are so many outside forms of apparatus

invented that the old skill of diagnosis is being weakened, and in some places a person called a diagnostician is appointed to perform all these extraneous things and avowedly to help the surgeon. Present-day medical students are not taught as thoroughly as they were that they have five senses, and they are not made to use them. They are taught the use of elaborate and expensive mechanical appliances, the learning of the manipulation of which takes a very large part of their time which would be far more usefully spent in looking at, touching, and listening to the patient, who, after all, is the real object of his concern, and whom he should be striving to understand. Anyone who has been privileged, as I have, to see some of the old great physicians at work will know what I mean. How a look at the patient seems to tell them almost at once where the trouble lies, which is the first step in the direction, which after all is the concern of the patient, of how he is going to get well, or what is going to happen to him—in other words, in quasi-scientific jargon, what is the Prognosis of the case. An instance of this power of observation, not in a doctor, but in a nurse, occurs to me. A patient under my charge was very ill with pneumonia, and I had gone round to the hospital to see her late one evening, and, finding her really extremely ill, and being very anxious about her, I asked the Matron, who before coming to us had been Sister of a big medical ward in one of our largest London hospitals, if she would come and look at her with me. After we left the ward she said, "She is just going to have her crisis," which proved to be the case.

To take only one instrument of modern times as an illustration of my point—X-rays. As I said before, they are most excellent servants but very bad masters. In many branches of medicine they are really essential, but they must always be used as an adjunct to clinical physical examination, and not in place of such examination itself.

Those physicians, and there are many at the present time, who trust to laboratory methods only, lose a most valuable method and source of diagnosis, viz. the patient's sensations. After all, let me again repeat, Medicine is an Art, and as

long as human nature exists it can never be a science, let alone an exact science.

As a clinical fact, diseases have their cycles. At one time the illness is much more serious than at another time, and *vice versa*. Sixty to seventy years ago scarlet fever was a most serious and devastating illness—whole families were wiped out by it. Measles, on the other hand, was regarded as something everyone must have, and a family of children, if one of their number caught it, were encouraged to mix freely with the sufferer. Now the two diseases have more or less changed places, and measles is by far the most serious illness of the two. In the same way, quite apart from the question of vaccination, the type of smallpox in the recent epidemics has been so mild that the mortality from it has been very small indeed.

Then different habits and customs bring about different illnesses or physical disabilities. The motor-car is responsible for a great many troublesome ills of the present day—rheumatism in the right arm and shoulder is often the lot of the driver who must have the window open to enable him to put out his arm in the traffic. Then the draught on the neck and shoulders has resulted in much more rheumatic thickening and lumps in those regions. The effect of the continued pressure of the hard ridge of the car on the thighs causes the same condition in those who spend a long time sitting in the car. The disinclination one finds in so many motor-car users for walking is probably due to the discomfort caused thereby, and not to laziness.

Again, prize-fighters and runners and those who indulge in over-active exercises suffer in the same way from this same condition of muscles—call it rheumatism, or call it by a better name, fibrositis—and, like the motorist, require the same modern methods of treatment, massage and various forms of electrical appliances.

All these observations are made to show what a plastic, non-static thing Medicine is.

There is a great movement towards preventive Medicine at the present time, and it is perhaps more specially concerned with private than with public health, with the individual rather

than the community. Such things as Maternity and Child Welfare Clinics, School Inspection and School Clinics, Tuberculosis Dispensaries and Sanatoria, Venereal Disease Clinics, and so forth, are examples of the present-day trend. Also the investigation now being carried out into the causes of Maternal Mortality. All this is emphatically to the good, and is a most hopeful import, and is to be highly commended.

All this concentration on individual health is regarded as a danger by some thoughtful people, and it must be confessed that it is not devoid of such a possibility. There can be no sadder sight than a man or woman whose mind is entirely occupied with his or her sensations of supposed ill-health. It cannot be too often reiterated that health is a want of consciousness of the body as such, when its mechanism is so perfect that its harmony is complete. But the great desire of everyone is that this state of harmony should be undisturbed, and is, I think, one of the strong arguments for well-directed health teaching, and even for regular overhauling.

Dr. Robert Hutchison has caused somewhat of a flutter in the dovecots of the American Medical Profession by a lecture in Winnipeg, at the recent visit of the British Medical Association to that city, on the "Pursuit of Health." It is severely criticized by Mr. Lee K. Frankel, the second Vice-President of the Metropolitan Life Assurance Company of New York, in a paper entitled "The Future of Medical Practice," given at the dedication of the West End Health Centre, Boston, U.S.A., on September 15, 1930. Dr. Hutchison's paper was certainly very provocative, no doubt intentionally so. He claims that the old state of ignorance of the body and its functions was a far more wholesome attitude, as well as a much happier state of mind. Dr. Hutchison said that the present modern pursuit of health had developed three types of hypochondriases —individual, vicarious, and national. Individual anxiety, or let us perhaps say care, is what we want to instil in a manner as wholesome as possible. In our opinion that is the direction in which Preventive Medicine lies. As vicarious hypochondriasis he instances the over-anxiety nowadays displayed by parents about their children. As he says, the rearing of an infant nowa-

days requires the combined knowledge of a chemist, a psychologist, and a public health officer. In these days of small families it is only natural that parents should display the utmost anxiety that the one or two should have what they feel to be the best possible chance, and many of them have probably gone to the opposite extreme. There is a time when wholesome neglect is good, but then it must be wholesome.

With regard to national hypochondriasis, Dr. Hutchison criticizes adversely the health societies, health weeks, baby weeks, booklets, leaflets, and various slogans, and finally states that no one should see a doctor till there is something the matter with the working of his human machine. Now there is enough of truth in all this to compel us to study it seriously. There is no doubt that the less people think and talk about their bodies the better. There is such a thing as healthy-mindedness, and it is a most valuable quality, and when it is lost there ensues a state of morbidity which is very difficult to combat and moreover singularly unattractive. It is this state of mind that is responsible for the bad side of the modern pursuit of health. There is a most harmful tendency to exploit for gain all kinds of so-called cures before they have undergone thorough and painstaking investigation. Their name is legion, all kinds of inoculations, all kinds of electrical treatment; psycho-analysis, ultra-violet rays and infra-red rays, sour milk, hormones, and many others. These things, probably most of them, have their uses in certain limited areas of treatment, but none of them by a stretch of imagination can be said to be in any real sense a panacea for all ills.

All these crazes are largely the fault of the public, but the medical profession is not without blame. They use these things and boost them. Manufacturers of the implements and apparatus get to work to perfect them, and a complete system of vested interests is evolved, and then, almost suddenly, one by one, they disappear, only to reappear as some new stunt. To take a somewhat homely illustration from a different region of activity. During the War everyone who could knit was making all sorts of wearable and unwearable garments for the soldiers. When the War came somewhat suddenly to an

end the manufacturers had huge stocks of wool on their hands. What could they do with it? Someone had the brain-wave of boosting the knitting of jerseys and jumpers for adults, and little knotted suits for children and infants.

Of course, along with all this comes the evil custom encouraged by the profession of manufacturing chemists inventing "cures," in tabloid or other elegant form, for all diseases under the sun, including the making of the old young.

All this I am convinced is purely temporary and fleeting. The Medical Profession, like everything else, is in the melting-pot, and we shall probably reach a stage when no drugs will be used except for the relief of symptoms, except, of course, in the case of a very few well-attested ones, which have been proved definitely curative.

We can see examples of these changes going on around us. Take anaemia—how rarely is a girl seen with that large white face that was so common twenty years ago. We doctors practically never see a case, and you lay people can test this every day for yourselves as you go by bus or train. Iron jelloids are still advertised on the steps of escalators, I believe, but the iron tonic has disappeared from the ordinary physician's consulting-room.

There is another section of the population also concerned with the question of both public and private health, and that is the nursing profession. Here drastic and serious changes will have to take place if that department of Medicine is to keep abreast of the times. Nurses will have to be organized into a really self-respecting body of people, with their own grading and status, independent of, and not subservient to, the medical profession.

Our hospitals, again, will have to be self-respecting institutions, not always going, cap in hand, to the public for money, and not ruining the whole system by the cheapness of probationer nurses.

I have a very shrewd feeling that the first thing to do with nurses is to put them on the same level as other women who are earning their own livings. They should not live in the hospital, but should have their quarters wherever they choose

outside, and go to their work like other people. The whole idea of nursing as a religious vocation, and therefore insufficiently paid, should be helped to go. At a recent meeting, when I was uttering some protest about the pay of an assistant secretary, I was told that she was a nice girl who did not mind much what she got. Those nice girls will have to go.

How are we, then, in the future, to ensure national and individual health?

Whatever scheme is finally adopted, its meshes must be fine enough to include everybody, particularly that large body of people who generally escape, the people with really moderate incomes. To these people a serious illness in the family is a financial disaster which probably cripples them for long after, making holidays less good and more scarce, and cutting down other amenities all of which are conducive to a state of good health.

Two schemes are before the public at the present moment: (1) The British Medical Association's proposals for a General Medical Service for the Nation. (2) The scheme of the National Medical Service Association.

Ever since the cessation of the Poor Law in April 1930 and the taking over of health functions by the County Councils, it has been realized that a complete public National Health Service was bound to come. Indeed, we might go further back, to the passing of the Insurance Act in 1911, which really foreshadowed a full medical service applied to a section of the population under an income limit. There is a good deal of likeness between the education problem and the medical problem. Actually the elementary schools are open to every child in the community. A duke might send his children as well as the man with little or no income at all. But of course we know in actual practice that the duke's children go elsewhere, and formerly complaints were made that he had not only to educate his own children, but to pay for that of the children of his poor neighbours.

Now a full and complete national scheme for medical services for all would be very much like that, and in actual fact the more fortunate members of the population would *for a*

time employ the doctor or surgeon of their choice. But an organized Medical Service would have so many modern methods and conveniences at its beck and call quite unattainable to any private practitioner or nursing home, that the public service would undoubtedly be more in demand and so better able to meet the necessities of the general public. It is more than probable that before long everyone would be doing the same thing to the advantage of the general national health.

The two schemes (referred to above) have a great deal in common, only the British Medical Association's scheme is an attempt to reform themselves from within, and with a laudable desire to safeguard the interests of the Medical Profession. In passing, I believe there is no instance in history where a great body of people have been able to reform themselves from within. It is a safe rule to mistrust all experts. It is not for nothing I believe that a criminal is tried, not by a series of experts on his particular crime, though, of course, they can help, but the decision finally rests on the opinion of twelve quite ordinary men and women.

Again, considering that people with incomes below £500 per annum form over 90 per cent. of the population, it would seem desirable in the interests of economy in every direction to aim at including the rest of the nation.

The two schemes may be briefly summarized as follows. Both desire that every kind of service which may be necessary for the prevention and cure of disease, and for the promotion of full mental and physical efficiency, should be at the disposal of every member of the community. To this end every member of the community must have his or her family doctor who is in the first line of defence. Stress must be laid on his power to assist in the prevention of disease.

The point at which the two schemes part company is in making the scheme contributory. That at first sight and to the inexperienced is attractive, but taking the analogy of education once more it will probably not work.

To sum up. Whereas in the past the treatment of disease has been the main duty of Medicine, now, and in the future, its main concern must be with prevention of disease. It will be

more concerned with maintaining the health of the community than with treating its diseases. Every scheme and method helping towards this ideal is to be commended, always bearing in mind that such schemes must be really sane and constructive, never forgetting that Medicine, whether it be curative or preventive, can never be an exact science.

BIOLOGY TO-DAY AND TO-MORROW

by JOSEPH NEEDHAM, M.A., PH.D.
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It seems to me that the discussion of biology to-day and to-morrow is a futile occupation unless we have in our minds also the state of biology yesterday. For one of the most distinguishing marks about the civilization to which we belong is just that capacity for seeing ourselves as one unit in a time-chain of other units, reaching backwards, as it were, down a brightly-lit tunnel, and forwards into impenetrable darkness. To men of other races and other times, this idea of the historical succession does not seem to have been possible. Those acquainted with the Greek mind, for example, tell us that the Greeks imagined the past to be placed behind them just as a painted curtain is placed behind a player on a stage; they had very little feeling for perspective either in the past or in the future. But for us, who see ourselves as the essential links between the biologists of yesterday and the biologists of to-morrow, it is absurd to neglect the former, and we must study their errors no less than their correct conclusions if we wish to avoid falling into errors ourselves. And, above all, the lesson of history is the lesson of the open mind.

In ancient China and ancient India and ancient Assyria there were no doubt biologists, or men who under better conditions would have been biologists, but we know practically nothing about them, or about what they discovered. They were overwhelmingly handicapped by the lack of a tradition. They were generally desirous of keeping their knowledge to themselves, and even if they had wished to make it public it would have been difficult or impossible to get in touch with other similarly minded men. It is to Greece, as usual, that we owe the first springtime of biology, the beginnings of an ordered attempt to get some understanding of what life is and how it works. The nature-philosophers of Ionia, who all lived between 600 and 400 B.C., each contributed something; their

knowledge and speculation was welded into a vastly greater structure by the two gigantic figures of Hippocrates the physician and Aristotle the philosopher; and in the later Hellenistic period, from 200 B.C. to 200 A.D., a high and steady level of investigation was maintained by a large number of workers, culminating in the anatomist Galen.

The curious thing about all this was, however, that it was largely speculation. A great part of it was pure speculation, building only remotely upon facts, and only kept close to possible truth by that almost miraculous quality of sanity that the Greek mind possessed, a quality which prevented the speculations from getting really wild. But these ancients did not understand the value of experiment, and if from time to time the experimental method flourished a little, as at Alexandria in the first century B.C., it was not appreciated, and the workers really preferred to argue. Observation, in fact, had been the great discovery of the Greeks. It was realized by Hippocrates, whose penetrating insight was devoted to the observation of human diseases. It was realized by Aristotle, who observed the appearance and behaviour of a wide range of animals and plants. But where experiment differs from observation is that you do more than merely observe once, you change the conditions in some way, you actively interfere with the course of nature, and then you observe again. This active interference was never appreciated in all its importance by the ancients. The natural aptitude of the Greek for argument and speculation was perhaps encouraged by the fact that biology, as always in its beginnings, was associated with medicine, and in medicine, where human beings are concerned, even to this day we are unable to do much more than merely observe. It might be said that Aristotle's dissections were examples of the experimental method, in that he observed, dissected away some intervening structure, and then observed again. But this was space-experimenting, and it is the time-experimenting which is important. As I said just now, the Greek mind had little feeling for time, and we cannot be surprised that it did not see the value of observing, changing the conditions and waiting, and then after the lapse of so much *time*, observing again.

It follows from the largely speculative character of ancient science that belief played a considerable part. You were either a follower of Epicurus, of Zeno, or of Aristotle. If you followed Epicurus you believed that in mammalian generation there were two seeds, one from the female, the other from the male; if you followed Aristotle, you believed that there was only one seed, the male, and that the female provided menstrual blood, out of which the embryo was formed. You did not attempt to see for yourself which of the two views was right. And nobody did until Dr. William Harvey, of my college, sixteen hundred years later, being physician to the King, and having the opportunity to dissect the animals killed in the chase, opened the uterus of pregnant does and found no yolk-like mass of blood therein.

It also followed from the speculative nature of the old biology that it ran to no form of biological engineering such as we have to-day, and shall have still more of to-morrow. Greek life was divided strictly into theory and practice, and perhaps it was because the latter was not thought fitting for a man of good birth, that so little was done to apply knowledge for human uses. A friend of mine, who is an historian, tells me that down to the end of the Roman period the artillery in use remained precisely what it had been six hundred years before, although the Empire was crumbling under barbarian pressure, and would have given anything, one would imagine, for an improved artillery capable of withstanding the Gothic armies. Again, it is strange, as Naomi Mitchison says, that the Romans never invented anything so much in the Roman taste as a railway. And as the biological example, it seems clear that ancient surgery benefited almost nothing from the thought and speculation of the biologists. The surgeon remained a member of the painter-cobbler-builder group, the group of low-born base mechanic men, entirely distinct from the astronomer-mathematician - metaphysician - biologist group, the group familiar with courts and tyrants.

Plato said that kings should be philosophers, and that knowledge was power, but he meant knowledge of the good. It would have been inconceivable to the Greeks that knowledge

should mean natural science, knowledge of causes and effects in the sense of Francis Bacon. And with mention of Bacon we come up with a rush to our own time and to the future. For the Middle Ages hardly concern us; they were a period in which the religious genius flowered luxuriantly, and in which men repeated scraps of the ancient writings on the rare occasions when it occurred to them to take some interest in the external world. But the renaissance brought in the new idea of the time-experiment, not only the speculations and space-experiments of the ancients. Kant knew what he was talking about when he wrote, "When Galileo rolled balls down an inclined plane, a new light burst upon all investigators of Nature." As Collingwood says, "The manipulation of Nature is the matrix and touchstone of modern science." And so in modern biology we do not simply sit and watch the procession of life phenomena that passes before our eyes; we actively interfere with it, we cut off a limb and see if it grows again, we remove a gland and see whether the results can be reversed by injecting extracts of the gland made in various ways, we find that liver will cure anaemia in rats, and we reduce the liver to ashes so that nothing but inorganic substances are left and then try again. We chart out, as it were, the effects of an enormous number of variables on each other. We take, perhaps, the eggs of seven different kinds of animals, a worm, a frog, a fish, a sea-urchin, a bird, a lizard, a rabbit, and we notice what occurs when we act upon each with ultra-violet light, X-rays, undue degrees of heat, undue degrees of cold, electric currents, changes in acidity of the medium, gases, and all kinds of other chemical substances. And these may act upon the developing embryo all the time, or only at some particular time, and they may be of any desired intensity, sometimes high and sometimes low, and they may be made to act, not perhaps on the embryo as a whole, but on particular bits of it. Out of all the masses of results which we accumulate by changing these variables experimentally, and which we try to express in mathematical form with graphs and nomograms, we derive a few fundamental relations, which hold for all embryos of a particular class, or maybe for all embryos whatsoever. To instance one

of these rules, it may be said that at the point in embryonic life called "gastrulation," when the developing creature undergoes profound changes in shape, which may almost amount to turning itself inside out, it also undergoes changes which make it extremely susceptible to external agents such as X-rays. A dose which will kill an embryo during the gastrulation period will have no effect at all on it at any other stage. And there are other "critical periods" which embryos go through, points at which a given external attack will have much more severe consequences than at any other time; points, too, let us remember, which each one of us in this room went through long before we were born. Nothing of this could have been found out by sitting tight and recording observations; the experimental method alone is capable of unravelling the causal connections between phenomena. The speculation of yesterday has given place to the experimental method of to-day, and one of the few prophecies we can venture to make concerning the biology of to-morrow is that it will be experimental.

The history of biology seems to consist largely of the slow and gradual clarification of questions. By this I mean that only with great difficulty did biologists come to find out that some questions have no meaning, and that it is useless to ask them because no answer is possible. Even at this day a good many of the problems which we cannot solve may be seen by the biologists of to-morrow as problems which were insoluble because the terms of the question did not make sense. But in the past we can see the process occurring time after time. I can best illustrate it by referring to the expulsion of ethics from biology, the gradual realization that good and bad, noble and ignoble, beautiful and ugly, honourable and dishonourable, are not terms which fit in with biological terms. Ideas of good and bad entered biology partly under the concept of "perfection." In 1260 Albertus Magnus,[1] one of the greatest investigators of the Middle Ages, maintained that male chicks always hatched from the more spherical eggs, and female chicks from the more oval eggs, because the sphere is the most perfect of

[1] Albertus Magnus: *De Animalibus, libri xxvi*, ed. Stadler, Münster, 1916.

all figures in solid geometry, and the male the more perfect of the two sexes. We realize to-day that to ask which is the more perfect of the two sexes is a meaningless question, for we have expelled ethics from science and cannot regard any one thing as being more perfect than anything else. Again, describing the course of the arteries in the developing chick, Albertus says, "One of the two passages which springs from the heart branches into two, one of them going to the *spiritual* part which contains the heart, and carrying to it the pulse and subtle blood from which the lungs and other spiritual parts are formed; and the other passing through the diaphragm to enclose the yolk of the egg, around which it forms the liver and stomach." This distinction between the organs above the diaphragm, the lungs, heart, thymus, etc., called *spiritualia* (*spiritualia in thorax sunt*), and the organs below, the stomach, liver, intestines, spleen, etc., runs through the whole of the early anatomy. It was if the organs of the thorax were regarded as a respectable family living at the top of an otherwise disreputable block of flats. To us it seems absurd to call one organ more "spiritual" than another, but that is because we realize the irrelevance of ethical issues. St. Thomas Aquinas, about the same time, in his famous *Summa Theologica*,[1] dealt in passing with human generation, "The generative power of the female," he said, "is imperfect compared to that of the male, for just as in the crafts the inferior workman prepares the material and the more skilled operator shapes it, so likewise the female generative virtue provides the substance, but the active male virtue makes it into the finished product." This is really the pure Aristotelian doctrine which I mentioned before, namely, that the seed of the male works like a ferment in a mass of inert material provided by the female, but St. Thomas gives it the characteristically medieval twist. Aristotle might make a distinction between form and matter in generation, but the medieval mind, with its perpetual hankering after value, would at once inquire which of the two, male or female, was the higher, the nobler, the more honourable.

All these notions were crude enough, but a subtler intrusion

[1] Thomas, St., of Aquin: *Summa Theologica*, Part III.

of the meaningless into biology can be seen in the idea of purpose which common sense naturally associates with living animals. Aristotle counted among the causes which act in nature, not only events which take place before any given event, but also events which take place after it. Thus the development of a chicken in its egg is not simply pushed forward by preceding happenings, but also pulled on by a force acting, as it were, from in front. This pulling force, radiating from the future, was supposed by Aristotle to emanate from the appropriate end-in-view, or to be analogous to the idea of the sword in the mind of the swordmaker, before the sword was made. Moreover, the end-in-view was supposed to be the divine idea of the perfect cock or the perfect hen, which presided over the incubation and brought it successfully to its conclusion. Obviously these conceptions were bound to lead to great difficulties. If the causes of a given event are not all situated in the past, then science must abandon the hope of giving a complete causal explanation of it, since we cannot observe the future until it ceases to be the future and becomes the present. If the embryonic development is like swordmaking, then the idea of the complete chick must exist in some sort of unconscious mind attached to the egg, which we cannot observe at all. And finally, if the pulling force is the "perfect" chick, we may well ask what a "perfect" chick is. We can identify the "perfect" chick with the "normal" chick, but by the very fact of our doing this we divest the idea of its ethical meaning, and give it a biological meaning instead.

During the eighteenth and nineteenth centuries a considerable proportion of the shareholders of biology (if we may use the language of the stock exchange) were theologians. It was felt that there was no sharp dividing line between religion and science, and that in every small detail of the visible world some evidence could be found for the central dogma of natural religion, the belief in a just and beneficent God. Biology was thus not free from the mental bias associated with theology.[1] Between 1700 and 1900 a multitude of books were written which purported to reveal the wisdom and goodness of God

[1] For a striking example of this, see Edward Gosse's *Father and Son*.

in the natural creation. But with the course of time it came to be seen that nothing but harm was done by mixing up theology with science in this way. The theologians took what suited their purpose and left the rest. It is instructive to see how Goethe, who was deeply committed to the theological interpretation of phenomena, reacted to the ornithological anecdotes of his secretary Eckermann on October 18, 1827.[1] He said little while Eckermann told him about the habits of the cuckoo, and other birds, but when Eckermann related how he had liberated a young wren near a robin's nest and how he had found it subsequently being fed by the robins, Goethe exclaimed, "That is one of the best ornithological stories I have ever heard. I drink success to you and your investigations. Whoever hears that, and does not believe in God, will not be aided by Moses and the prophets. That is what I call the omnipresence of the Deity, who has everywhere spread and implanted a portion of His endless love." And so it always was with the theological naturalists, they hailed with enthusiasm the discovery of monogamy in tortoises, or mother-love in goats, but they had nothing to say concerning the habits of the hookworm parasite, or the appearance of embryonic monsters in man. We see clearly to-day, however, that nature cannot be divided into the Edifying, which may with pleasure be published, and the Unedifying, which must be hushed up. The theological bias has gone from biology.

We have seen the futility, then, of one kind of meaningless question, "Which of the two sexes is the more perfect?" A second variety, "What does such and such a phenomenon teach us about the goodness of God?" is equally futile. A third sort of question which is futile, because meaningless, is, "Why does that insect want to fly towards the light?" but this requires a little explanation. The question is pointless because it involves the fallacy of personification. We assume gratuitously that the fly has a conscious interior life just like our own, and we exalt it into a person, complete with wants and desires like ourselves. We all admit that the personification of such a thing as

[1] Eckerman, J. P.: *Conversations with Goethe*, Everyman edition, London, 1930.

the west wind is a poetical gesture, but to the ancient Romans such personifications were much more serious, and the deities of natural forces had each their altars, their sacrifices, and their priests. Similarly in the seventeenth century, when chemistry was beginning to assume its modern form, acids were believed to be male and alkalies female. The word "quicklime" is a relic of this period, a relic of the time when lime was thought to be alive, and to resist with violence the efforts of water to quench it. But as chemistry developed, these personifications were found to be useless, as what went on could be more expeditiously and clearly described without them. They joined the west wind in its literary limbo, and the only reason we hear so much less of them is that poets so seldom choose the titration-curves of acid-base mixtures for their theme. But the process of depersonification once begun, where was it to stop? Obviously, people said, at the step between life and non-life, for all life would possess mind. But this step has been growing more and more indistinct during the last hundred years, and now we can hardly find it. Between the largest non-living colloidal particle we know, and the smallest visible living bacillus we know, there is a region of limited extent which is at present full of mystery. But we can say this about it, that it contains a good many organisms which are more or less living. Of these the most famous is the bacteriophage, which is the active agent of a disease to which bacteria themselves are subject, but all the filter-passing viruses, the invisible particles which pass through all but the finest filters, are included in this region. We know them by their effects, pathological or otherwise, but of their relations with the non-living particles which are so slightly smaller than themselves, we know practically nothing. It is still possible that they may be generated every day in myriads from definitely non-living matter, or, on the other hand, they may obey the general rule and originate only from their like. But as regards personification, are these minute bodies to be endowed with minds? Where is the process of depersonification to stop? If the filter-passing viruses may be regarded as mindless, why not the protozoa, and if not the protozoa, why not the higher animals? In other words, there

seems no reason why, if he found it useful, the biologist might not assume the absence of mind in animals and man. And the remarkable thing is that he has found it useful to do so. Modern experimental psychology and physiology, in the schools of Watson and Pavlov, has made great progress in what we may call the mechanization of consciousness. We find that we can explain animal behaviour much better by leaving out voluntary actions, desires, strivings, etc., than by putting them in, and the personification of the insect in the original question is more hindrance than help. It does not want to move towards the light, or to move any other way; it moves because it has to. For science, living organisms are mindless machines.

Meaningless questions, then, are the great stumbling-blocks of biological thought, and slowly disappear, one after another, as science progresses. To-day the biologist has developed quite an instinct for concentrating on the questions which it is likely that he can answer in a reasonable time. This is why we hear so little now about the Origin of Life. No one can go backwards in time to find out how it originated, and all that speculation can do is to travel round a well-worn circle of suppositions which lead us nowhere.

It seems strange that we should get any insight into the future by looking at the past, but by studying the biology of yesterday we have succeeded in distinguishing two principal characteristics of the biology of to-morrow. Firstly, it will be experimental; secondly, it will continue the process of distilling and redistilling its questions, leaving behind the meaningless residue each time. To these we can add prophetically a third feature: the biology of to-morrow will be quantitative, the biology of to-morrow will be statistical.

It is a curious fact that scientific questions, even those which do have meaning, never get answered until accurate measurement is brought to bear on them. Thus in times past it was thought that the only important constituents of food were the very obvious ones, which it contains in large amounts, such as fats, sugars, etc. It was not until Hopkins[1] made the experiment

[1] Hopkins, F. G.: *Journ. Physiol.*, 1912, vol. 44, p. 433.

of keeping rats on an artificially made diet and weighing them each day to see whether their growth was normal, that vitamins were discovered. Something subtle was evidently missing, something essential was absent from their food, for the growth curves fell off and began to decline. I shall show you Hopkins's classical diagram (Fig. 1), for apart from its intrinsic interest

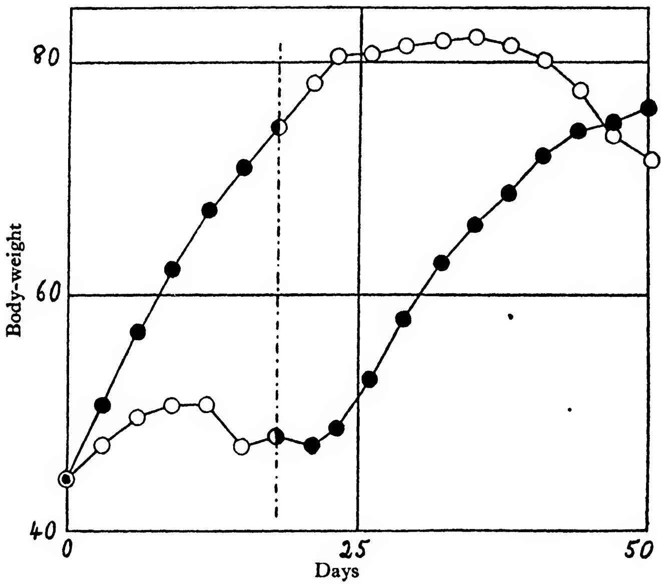

FIG. 1

Hopkins's classical diagram showing the evidence which led to the discovery of the first Vitamin.

it illustrates perfectly the theoretical importance of accurate measurement.

The weight of the animal is measured along the vertical axis, the time in days from the beginning of the experiment, along the horizontal axis. Hopkins fed young rats on an artificial food mixture consisting of casein (the protein of milk), starch, cane sugar, lard, and salts. When the animals were fed upon the diet composed of these constituents in the

crude condition they were able to live and to show a certain amount of growth. When, however, the substances had been carefully purified, growth always ceased after a comparatively short period, and the rats declined and died. Hopkins made sure that this was not merely due to insufficient food intake. They ceased to grow at a time when they were consuming food in more than sufficient quantity to maintain normal growth (this is shown by the lower line of white circles in Fig. 1). But another series of animals received in addition to the daily ration of purified foodstuffs a very small daily allowance of milk, amounting to only 4 per cent. of the total solids in the food. Yet this addition, as appears by the left-hand line of black circles in Fig. 1, permitted of normal and continuous growth. Finally, the two sets of animals were changed round, the milk being given to the animals which had been failing to grow and withheld from the others. Accordingly the effect was reversed. In this way the accessory factors in the food, or as we now call them, the vitamins, were discovered. But without the accurate measurement of the weights of the rats nothing would have been found.

We know now that accurate measurement is one of the foundation-stones of pure science, something that science cannot do without, and which makes science seem distastefully cold and calculating to poets and theologians. The scientific worker in general, and the biologist in particular, is always pining after exact knowledge, and the only way to make anything exact is to give it a set of units, to force it into a numerical form, so that what happens in it or to it can be expressed mathematically. It has been said that what interests the scientific worker first and foremost about anything is the size, the dimensions, the magnitude of it, and what he finds even more interesting is to know whether this magnitude is changing with time, getting smaller or bigger, and what finally interests him most of all is to know whether this change, if it exists, is altering its rate, that is to say, getting faster or slowing down. To find regularities in the kaleidoscopic chaos of events is his one and only aim.

As another example of quantitative regularity we may

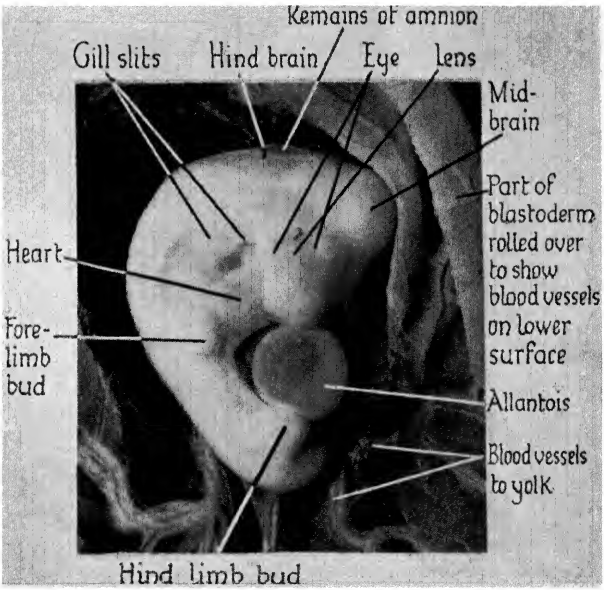

FIG. 2
A chick embryo of four days' incubation.

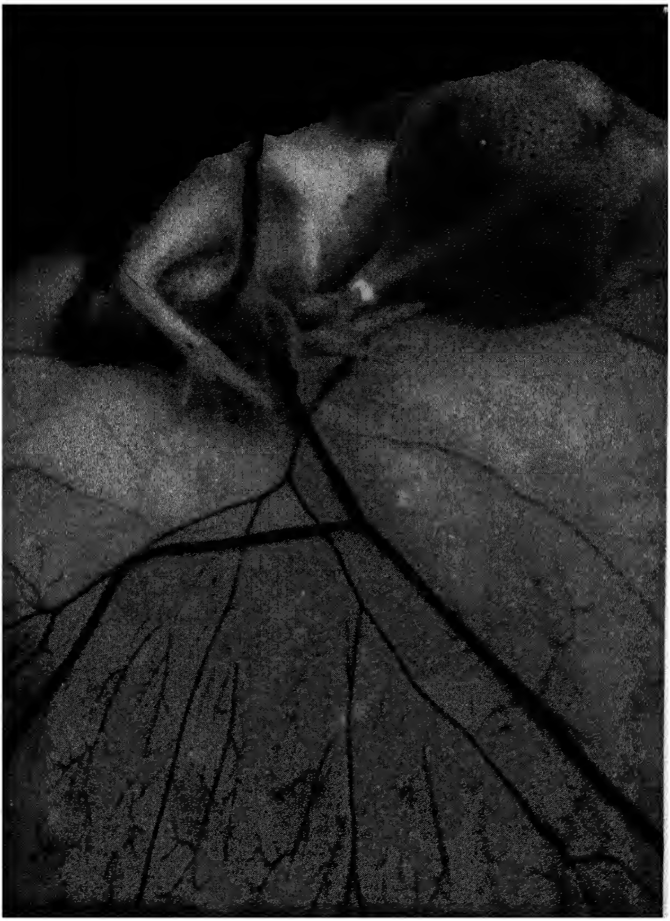

Fig. 3
A chick embryo of eight days' incubation.

consider the excretion of nitrogenous waste-products by the chick embryo. The chick embryo, during the three weeks which pass between the beginning of incubation and the time of hatching, grows and develops as the original yolk and white are transformed into the bones, blood, skin, feathers, muscles, and organs of the finished product. But during this time it is not only growing, it is also eating. It does not eat by means of its mouth or beak, which is not yet sufficiently developed, but it absorbs through its blood-vessels the nourishment from the yolk. This kind of eating goes on at an extremely rapid rate, especially in the early stages; thus on the sixth day after development has begun the embryo absorbs more than its own weight of dry substance. This would be equivalent to a mature man eating about 150 pounds of food in one day, or, if he were a cannibal, one other member of his own species, complete in every detail.

No living organism can burn the whole of the food which it eats, and if ingestion of food takes place, it follows that there must be excretion of waste-materials which the body cannot use. The three chemical substances, ammonia, urea, and uric acid, are the principal forms in which the waste nitrogen disappears from the animal, and as the chick is developing in a closed box, the egg, some provision has to be made for storing these excreta until hatching takes place. This is done by means of the extra-embryonic bladder, or allantois. Fig. 2 shows you a chick embryo of four days' incubation. It lies upon the yolk, and its fore-limb and hind-limb buds are observable, together with the beginnings of the eye and brain. The allantois appears as an almost spherical bag, growing out from the hinder end of the chick's alimentary canal. As development goes on, this transparent bag grows tremendously and encircles the embryo and yolk. Fig. 3 shows a later stage; the embryo rests on the surface of the yolk, but between us and the yolk-sac there are, as it were, the two transparent sides of a bag. It is in this bag that the waste products accumulate.

The point is that their accumulation follows a perfectly regular course. We can find out how much of each of them there is at any given time by taking the allantoic fluid and

passing it through more or less complicated chemical processes.[1] And having found out by means of such "estimation-methods" how the accumulation goes on, we can compare this with the growth of the chick itself, and we can thus calculate the rate at which any of the substances is being excreted. By these means we derive the picture seen in Fig. 4. The horizontal scale gives the time in days between fertilization and hatching, the vertical scale gives the amount of nitrogen excreted by the embryo each day. (The latter is expressed in logarithmic form simply for convenience of drawing; if it were not, it would be impossible to get all the figures on to the same graph.) We see at once a very interesting relation; the excretion of ammonia (the smallest molecule) begins first, but never reaches such a high level as the others, urea excretion begins next and reaches an intermediate level, and finally comes the excretion of uric acid (the largest molecule), which soon overhauls the others and eventually accounts for one hundred times as much nitrogen as is excreted in the form of ammonia. There is thus a perfectly regular sequence in the appearance of the waste products. The sequence is, as a matter of fact, particularly interesting because it is also an evolutionary sequence, that is to say, the lowest animals tend to excrete ammonia, intermediate forms urea, and birds and reptiles uric acid. The excretion of ammonia is thus on a par with the so-called gill-slits which occur in every embryo of the higher animals at a certain stage in its development, and which betray its aquatic ancestry.

But this is a chemical example, and it has often seemed to some that although quantitative methods were applicable to chemical problems where atoms and molecules are under consideration, they were no use in biology as a whole. The nature of form, of shape, of anatomical structure, has sometimes seemed to be essentially immune from quantitative attack. The belief in an impassable gulf between morphology or anatomy and biophysics seems to me, however, to be simply a relic of the old Aristotelian distinction between form and

[1] Needham, J.: *Journ. Exp. Biol.*, 1926, vol. 3, p. 189; vol. 4, pp. 114 and 145.

matter, still lingering on in scientific thought. Modern morphology is more and more adopting quantitative methods,

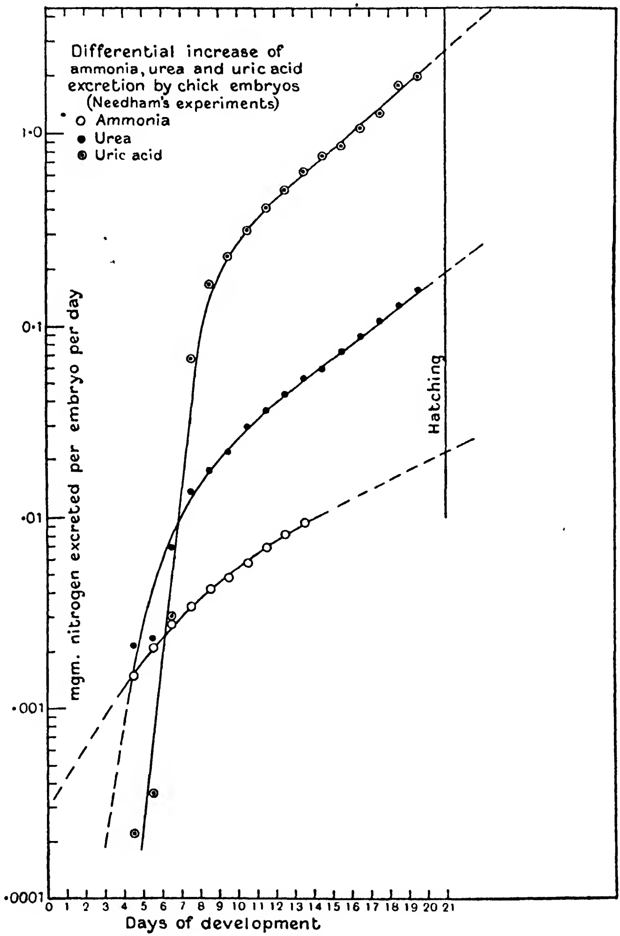

FIG. 4

and by so doing is aligning itself with biochemistry and biophysics.

The instance of growth itself would not here be amiss, since we have already mentioned it in several connections. Fig. 5 shows the growth of the mouse embryo according to the

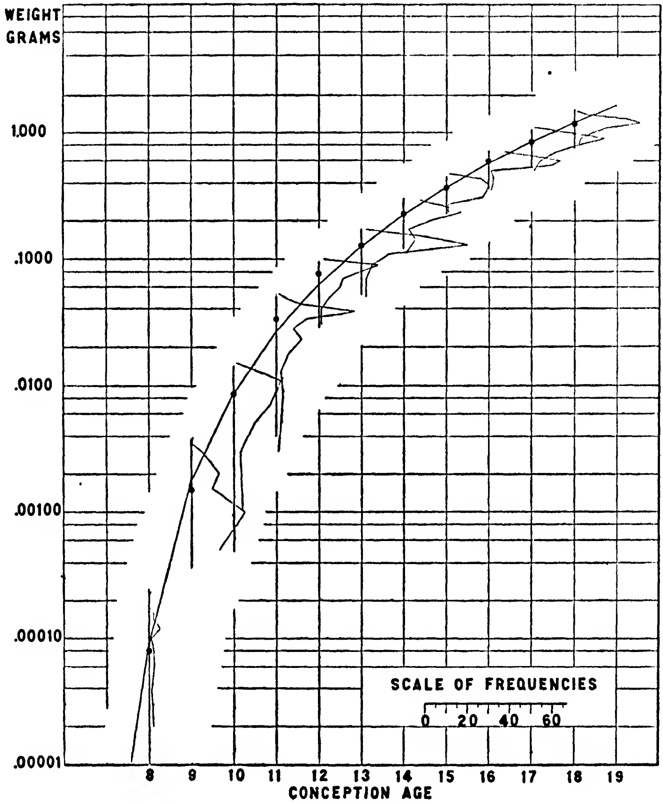

FIG. 5

The growth of the mouse embryo.

work of McDowell, Allen, and McDowell.[1] The vertical scale (in logarithmic ruling, for convenience) gives the wet weights

[1] McDowell, E. C., Allen, E., and McDowell, C. G.: *Journ. Gen. Physiol.*, 1927, vol. 11, p. 57.

of the embryos in grams, the horizontal scales give the age and the number of individuals. On each day the range of individual unclassified weights is shown by a vertical line, and this line is itself the base line for the frequency distribution of the classified individual weights. The number of cases in the distribution is shown by the distance of the frequency curves to the right of the vertical base lines. The means are shown by dots, and a line drawn through all the dots would give the empirical growth-curve for this population of mouse embryos. The curved line as actually drawn is that derived from a mathematical formula which these workers devised, and as can be seen, it does almost exactly coincide with the points—the worst divergences occur on the eleventh and twelfth days from conception. This instance exemplifies clearly the statistical character of biological method. One solitary isolated individual phenomenon is of no more interest to the biologist than the man in the moon, even half a dozen may not carry much weight, and it is not until we begin to deal with whole populations of facts that regularities and interesting relationships begin to appear. Thus it can be seen from Fig. 5 that on any one day there are easily to be found embryos which are of the same size or which may even be smaller than those of the day before. Judging from a few instances alone, it might be assumed that the mouse embryo remains the same size or even gets smaller with time, but as soon as we see the phenomena on a big scale these possibilities vanish. They only exist at all because living organisms, as one would naturally expect from their complicatedness, are exceedingly variable.

Growth is not all a matter of weight, however; there is growth in length and other dimensions also. To show how great a mass of data can be got into the form of graphs, I have in Fig. 6 a three-dimensional co-ordinate system constructed by Scammon and Calkins.[1] It gives the relations between body-weight, body-length, and age in human embryo. The left-hand horizontal scale gives the height, the right-hand horizontal scale gives the weight, and the vertical scale gives the age.

[1] Scammon, R. E., and Calkins, L. A.: *Proc. Soc. Exp. Biol. and Med.*, 1924, vol. 22, p. 157.

This is called an isometric projection, and from it we can read off the two remaining variables if we know only one. But much more complicated morphological facts can be reduced to order. In Fig. 7 we have a frequency curve (taken from the work of Scott[1]) showing the distribution of 700 observations on the number of gastric glands per square millimetre in new-

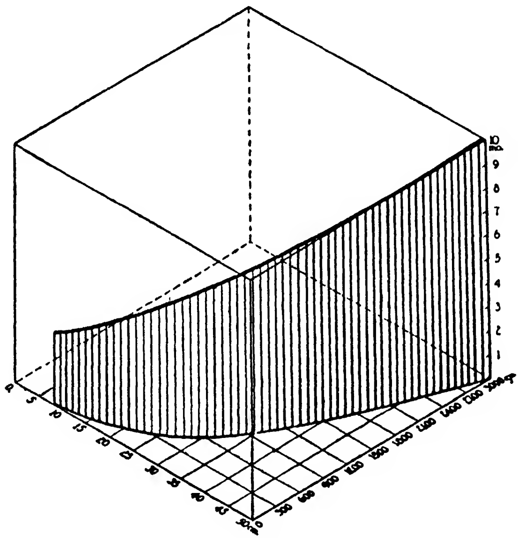

FIG. 6

The relation between body-weight, body-length and age in the human embryo.

born human infants. These glands are groups of cells, situated on the surface of tiny microscopic depressions in the stomach wall, and by their activity secrete the juices necessary for the normal digestion of the foodstuffs. In the graph the horizontal scale gives the number of glands present in the stomach wall per square millimetre at birth, and the vertical scale the number of individual cases. From this we see that the

[1] Scott, G. H.: *Amer. Journ. Dis. Childr.*, 1925, vol. 30, p. 147.

great majority of observations show 122 glands per square millimetre, but that in exceptional cases there may be as many as 150 or as few as 90. Once such a frequency curve is established, the effect of external agents on the phenomenon in question can be found out with some possibility of definite results, for the shifting of an individual case would not be

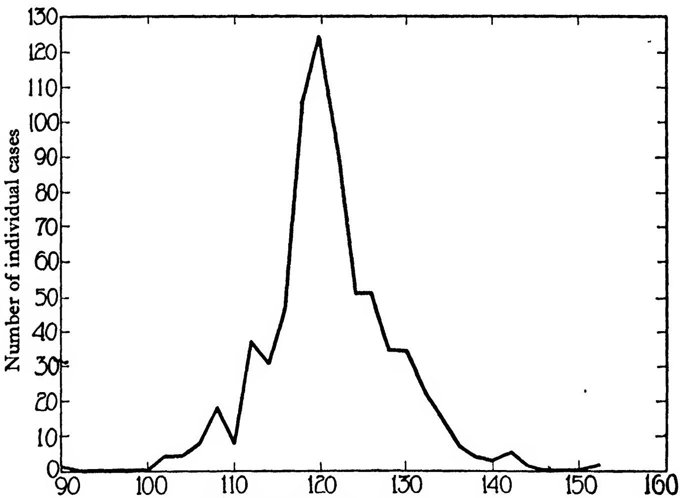

FIG. 7

The distribution of 700 observations on the gastric glands of the new-born human infant.

significant; only the shifting of the maximum point of the frequency curve would carry conviction. These curves also give important information when they show, as they sometimes do, two or more peaks, for then we are given a clue to the presence of two quite distinct groups of individuals in our population. This is the way in which the mixed nature of a population may be tested. Another very interesting diagram concerning the development of the stomach is seen in Fig. 8, also due to Scott. Here we see the different developmental

rapidities of such factors as the volume of the stomach crypts, their surface area, their number, and the number of glands. The vertical scale shows the percentage of the adult value reached at the times indicated beside the columns. Thus at birth the surface of the crypts and their number have grown,

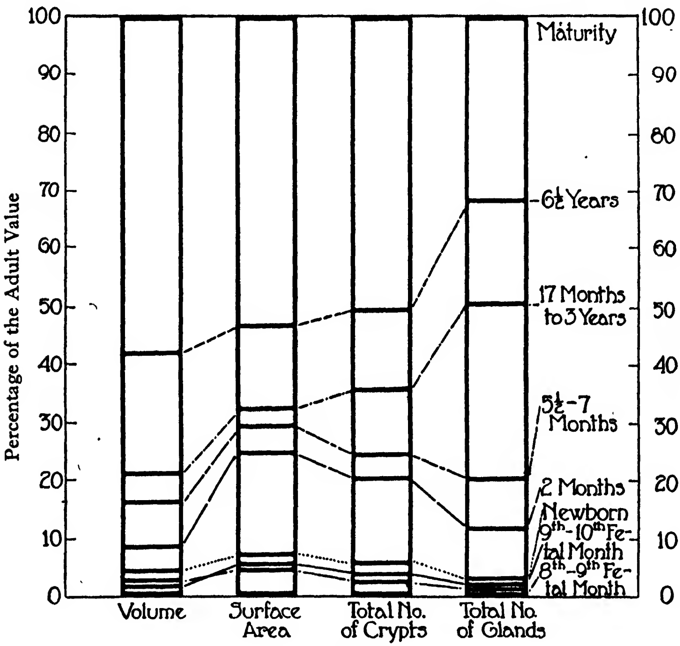

FIG. 8

Developmental Rates of various morphological factors in the human stomach.

as it were, faster, and reached a more precocious stage of formation, than their volume, or the total number of glands. This means in ordinary language that they are shallower than in the adult, and that they each contain on an average a smaller number of glands. In later development, up to six years, the number of glands has increased considerably, and has reached a higher percentage of the adult value than any of the other

factors. The way lies open for the accurate association of these relationships with physiological and chemical knowledge. And so throughout anatomy we can have a quantitative expression of the facts.

One of the most interesting applications of exact methods to morphology is concerned with the differences in shape

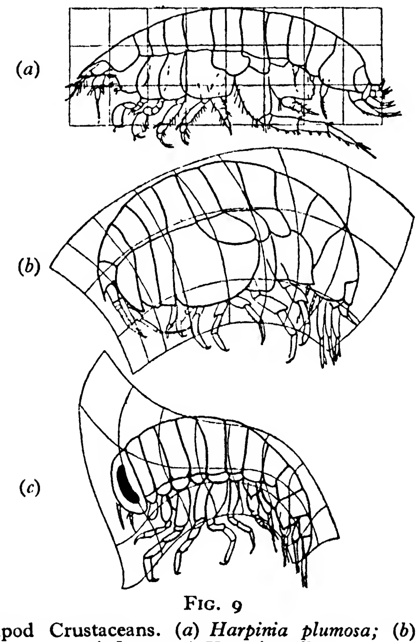

FIG. 9

Some Amphipod Crustaceans. (*a*) *Harpinia plumosa;* (*b*) *Stegocephalus inflatus;* (*c*) *Hyperia galba.*

between different animals. The comparison of related forms is a part of the theory of transformations. If we inscribe in a system of Cartesian co-ordinates the outline of an organism, however complicated, we are treating the complicated figure, in general terms, as a function of x, y. If, then, we submit the rectangular figure to deformation, pulling it out in one direction, or squeezing it in at one end, that it is to say, altering the direction of the axes, altering the ratio of $x:y$, or substituting

for x and y some more complex expressions, we obtain a new system of co-ordinates. And the remarkable thing is that the inscribed picture, which has been deformed in one way or another according to what we have done, will quite probably have a close resemblance to some other living organism allied

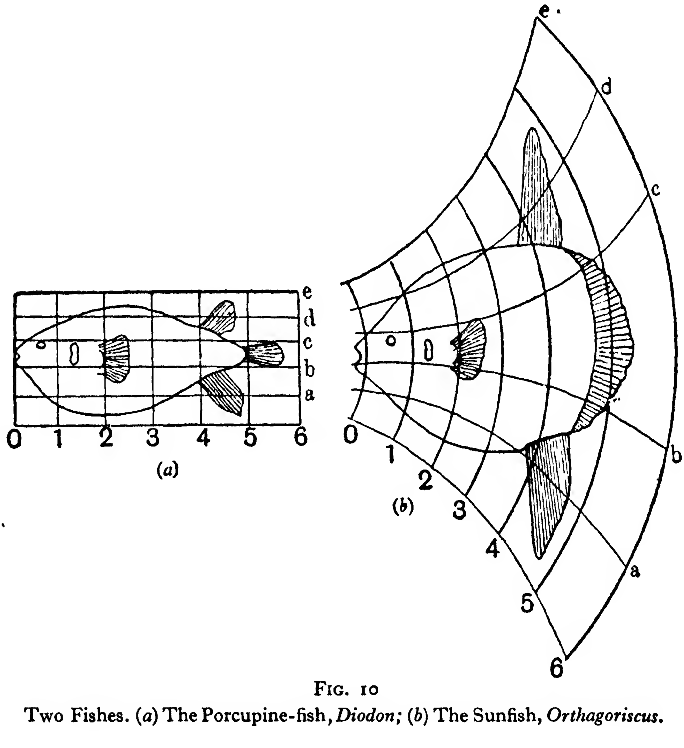

FIG. 10

Two Fishes. (a) The Porcupine-fish, *Diodon;* (b) The Sunfish, *Orthagoriscus.*

to the first one. The classical discussion of this subject is that of d'Arcy Thompson,[1] and I have selected two examples from it. Fig. 9 shows first of all a plain rectangular figure, next the same figure deformed in a double orthogonal curvature, and lastly the same figure with one end extended and the other end

[1] d'Arcy Thompson, W.: *Growth and Form*, Cambridge, 1917.

compressed. Each of these figures corresponds to a particular species of crustacean, for the uppermost one shows the amphipod *Harpinia plumosa*, the middle one shows another amphipod of a different family, *Stegocephalus inflatus*, and the third shows the aberrant *Hyperia galba*. The second and third of these pictures are nothing but the first picture under different, clearly definable distortions, and all three animals are functions of their co-ordinates in exactly the same way. Another example appears in Fig. 10, where the porcupine-fish *Diodon* can be transformed into the sunfish *Orthagoriscus* by a complicated transformation of the co-ordinate system (the abscissae

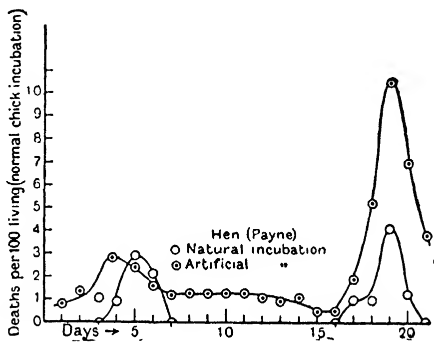

FIG. 11
Standard Mortality Curve for the chick embryo.

being turned into hyperbolas, and the ordinates into concentric circles). By such methods as this we can obtain a very satisfying summary of the unequal growth plans which exist in the different animals.

So far we have been dealing with the individual organism, but for the final example I shall take the survival of a whole collection of organisms. The interest attaching to mortality curves in biology is extremely great, for only with their aid can some of the most important problems of evolution and selection be approached. I mentioned earlier on that the developing embryo passes through certain stages at which any given degree of external interference with it is particularly dangerous. Fig. 11 shows how this occurs in the case of the

chick embryo. The time in days between fertilization and hatching is shown along the horizontal scale, and the deaths per hundred living are numbered along the vertical scale. A glance at the curve shows that the fifth day and the nineteenth day are particularly dangerous, and that the greater number of embryos that die at all die on those days. These curves (plotted from the work of Payne[1]) also show that incubation in the artificial incubator is less efficient than incubation under the hen, but we do not yet know in exactly what this superiority of the hen consists. As regards the cause of the two death-peaks, we know nothing for certain, but it is very probable that the early one is due to difficulties in breathing, for as the embryo grows it will need continually more and more air, and if the requirement is in danger at any point of exceeding the powers of the mechanism of supply at that time, suffocation may arise. As for the late death-peak, there are two possibilities: it may either be due to the change-over from water-respiration (air entering the blood directly through the shell), to air-respiration (the functioning of the lungs), or to a water-starvation, too much water having evaporated away from the egg into the surrounding atmosphere.

Although we do not know definitely to what these peaks are due, we can influence them by means of the appropriate action. Fig. 12, taken from Landauer's paper,[2] shows the curves of survivorship in a population of chick embryos. As they begin from the sixth day only, they do not show the early death-peak which was seen in the last slide. The topmost curve (small crosses) is that for normal incubation—it shows the dangerous late period by a precipitous drop of the curve, the number of survivors suddenly diminishing rapidly. The continuous line shows the effect of injecting small amount of a harmless salt solution into the egg on the sixth day; there is no change in the total mortality, but the rate of death is higher in the early period and lower in the late. On the other hand, if the same amount of a very dilute lithium chloride solution is

[1] Payne, L. F.: *Journ. Amer. Assoc. Poultry Husbandry Teachers and Investigators.*

[2] Landauer, W.: *Poultry Science*, 1929, vol. 8, p. 301.

injected, the early mortality is again high, but this time the late mortality is greatly increased too, and the number of survivors drops during the last critical three days to about 30 per cent. instead of the usual 70 per cent. Information of this kind may lead to an exact identification of the causes responsible

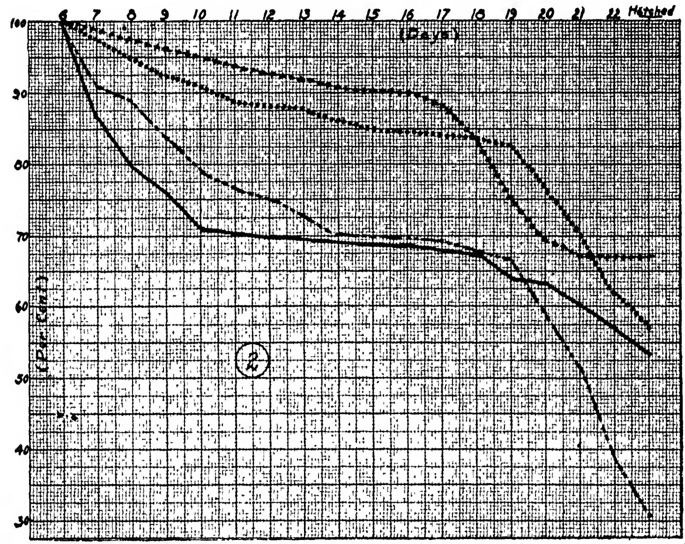

FIG. 12

Survivorship Curves for a population of chick embryos.

for the high death-rate at the end of development, and so no doubt to its prevention.

In taking these concrete illustrations for discussion it has simply been my design to emphasize the profoundly quantitative character of modern biology. We have to realize that behind these seemingly dry charts and diagrams there is real flesh and blood, the whole pulsating, active world of living organisms. The biology of to-morrow will be working in a very similar way, but the charts will be more complicated, the diagrams more intricate, and the generalizations, we hope, simpler. As times goes on, mere words become less and less adequate for

the descriptions of the states of affairs we meet with in nature, and as time goes on they will more and more be replaced by the kind of pictures[1] which I have been showing you, together with their mathematical formulation.

Let us now look round upon the biology of to-day. You will remember that in his Utopia, Francis Bacon[2] imagined a kind of benevolent oligarchy of scientific men, as if the government of the country should be in the hands of the Council of the Royal Society. The members of this oligarchy he called the "Fathers and Brethren of Solomon's House," and in the course of the narrative one of them gives an audience to the European visitors. He describes to them all the equipment and inventions which are at his command, the riches of Solomon's House. "We have," he says, "sound-houses, where we practise and demonstrate all sounds, and their generation. We have engine-houses, where are prepared instruments for all sorts of motions. We have also furnaces of great diversities, heats in imitations of the sun's heats, heats of dungs, heats of bellies and maws of living creatures, and instruments which generate heat only by motion. We have also parks and enclosures of all sorts of beasts and birds, which we use not only for view or rareness, but likewise for dissections and trials." Bacon's Utopia, *The New Atlantis*, was written in 1624; let us now examine the fruits of three hundred years of tireless labour, labour which has made the riches real, and Solomon's House no fable.

We have laboratories of Genetics, in which the extraordinarily complicated systems of heredity in plants and animals are studied. Here you may find whole fields of flowers, one being crossed with another, and chemical analysis made of

[1] Acknowledgments for permission to reproduce the pictures are due to Sir F. G. Hopkins and the Cambridge University Press for Fig. 1; to the Clarendon Press for Fig. 2; to the Cambridge University Press for Figs. 4 and 11; to Dr. E. C. McDowall and the *Journal of General Physiology* for Fig. 5; to Dr. G. H. Scott for Figs. 7 and 8; to Professor d'Arcy Thompson and the Cambridge University Press for Figs. 9 and 10; and to Dr. W. Landauer and *Poultry Science* for Fig. 12.

[2] Bacon, Lord: *The New Atlantis*, in collected works, ed. Ellis and Spedding, London, 1905.

the colours of their petals. Or there may be vast numbers of some insect, such as the fruit-fly, living out its life, generation after generation, in glass bottles, under strict supervision, so that the course of evolution can be observed in the laboratory, and the effect of external agents, such as X-rays or alcohol, can be tested. Side by side with large-scale experiments on populations there goes the microscopic analysis of the germ-cells, containing in their nuclei the material basis of heredity. And the combination of such lines of work leads to the preparation of actual maps of the heredity-controlling material, as if geneticists were geographers, and the chromosomes new continents.

We have laboratories of Embryology, where the development of the embryos of all animals can be followed, either in studying the manifold changes in form or the physical and chemical changes in the developing substance. Here you may see what is perhaps the greatest wonder in all biology, the transparent egg of, say, an echinoderm, looking like a structureless bead of the purest glass, and yet ready to transform itself, in a few hours, into a free-swimming larva of great complexity possessed of numerous organs and functions. In this laboratory, too, the works of grafting go on; pieces of tissue or groups of cells are taken from very young chick embryos and grafted into older eggs, so that by watching their development we can tell what the original unformed lump had decided to develop into. Or, in a great number of ways, development may be made to go wrong, and monsters may be produced; moreover, any given kind of monster may be produced by acting on the embryo at just the right time with just the right stimulus. Fishes with two tails, or frogs with many legs, are common objects here, and such processes throw much light on the events of normal development.

We have also laboratories of Biochemistry, Biophysics, and Physiology, where every function of every organ in the animal body may be subjected to accurate measurement. The speed at which the nervous impulse runs down a nerve may be found out to the nearest thousandth of a second in men, mice, or myriapods. The blood, that internal ocean, ever flowing round

the body, can be examined during and after every kind of varying condition, and most of its hundreds of chemical constituents can be accurately set down, as to how much, and in what proportion. The breathing of bacteria, their intake of oxygen and output of carbon dioxide, can be precisely ascertained, and the effects of all sorts of agents which alter respiration can be observed. In these laboratories we often see the extraction and identification of the active substances from the endocrine glands, and their purification, or even their synthesis from chemical substances of non-living origin. We have also laboratories of Pharmacology, where all kinds of tests are made of drugs, poisons, and active principles, so that their effects may be exactly known. We have also laboratories of experimental Psychology, where observation is made of the behaviour of living animals, to see, for instance, what simple problems they can solve, or whether the stimulus of reward and punishment has any effect on the ability of rats to find their way through mazes.

Next we have laboratories of Marine Biology. With its own fleet of boats, its own landing-stage, its own aquarium, its own physiological and chemical apparatus, the marine biological station is well equipped to search out the secrets of the sea. The workers here devote themselves to all the aspects of aquatic life, but also to the sea itself, and its composition, which varies considerably according to the season, the weather, and other factors. But for the deep-sea work such coastal stations are not enough, and from time to time we send out larger expeditions in research vessels, floating laboratories, to survey remoter regions. We have also laboratories and museums of Zoology, where dissections are made of all living animals, and where specimens are laid up in preservation to aid in the identification of rarer forms.

We have also laboratories of Agriculture, so that a more intensive study of the questions raised by that most ancient of works may be made. Then we have laboratories of Entomology, where each one of the thousands of different kinds of insects is known at sight, and laboratories of Parasitology, where the parasites which infest man and his animals are

studied so that they may be fought and destroyed, and where the parasites which infest the insect or plant enemies of man and his crops are also studied so that they may be encouraged. The parasites of man's enemies, indeed, are carefully reared in great numbers, and then liberated in some place where particular need exists. Again, we have laboratories of Bacteriology, where all sorts of microscopic organisms are kept and studied, and of Botany and Forestry, where everything that pertains to plants and trees is examined and investigated.

Finally, we have laboratories of Palaeontology, where no living animals are ever seen. This is because the workers here are wholly concerned with fossil creatures that died thousands of years ago. From their fragmentary remains—a bone here, a shell there—they reconstruct with great ingenuity the whole plan of the prehistoric animal.

All that is missing from this account of biology to-day is Francis Bacon himself. He would surely be delighted if he could see the riches of Solomon's House brought thus into actuality. But it is sad that the other admirable arrangements of *The New Atlantis* have not been brought into being too—the peaceful commonwealth, the grave and industrious people, the virtuous governors, the equally distributed wealth.

So much for the biology of to-day. We have been able to conclude that the biology of to-morrow will be quantitative, statistical, experimental. It will be, in some respects, more complicated, in others more simple. It will include even fewer meaningless questions than we have now. It will result in innumerable extensions of human power over nature, particularly in the sense of biological engineering. It will have some understanding of the nature of biological organization, an understanding which we at present have not.

And this is the last thing that I shall dwell upon. Central to biological science is the problem of organization, the problem of why living beings take the strictly arranged forms which they do, the problem of why cells group themselves into their complicated patterns. Why do the cells of a developing frog embryo form themselves into the neural tube, into a tube, and not simply into nondescript mass, such as they may

assume when cultivated entirely outside the body? This is the kind of thing about which we know at present almost nothing. The organization eludes us, and although we can do all kinds of things with the living creature, we do not understand the nature of the organizing relations which hold it together and make it an organism. There is nothing essentially mysterious about these organizing relations, they are only mysterious because we have not developed the mental machinery capable of getting to grips with them, and it is possible that physics will have to make still further advances before it becomes possible to develop it. Organization in animals and plants, after all, is an analogous thing to crystallization in the inorganic world, for there also, as in the delicate tree-like structure of ice-crystals on the window, we have a higher form of organization than the rushing hither and thither of the molecules in the liquid water. An element of drill has entered in, an element of order, and it must be just the same with the very different and much more complicated organization of the living organism. It is as if Nature had always had something else up her sleeve than crystal form, namely, organic form. But its understanding is for the future.

If I end by emphasizing the major unsolved problem of modern biology, it is for the same reason that I began by emphasizing the finished work of ancient biology. The past did not begin yesterday; the future will probably not end to-morrow, and we must see ourselves as the links in a very long chain. This prevents us from supposing that Wisdom was born with us, or that we are the Highest Product of Evolution, the crowning achievement of the Universe.

MECHANISM—THE FOUNDATION OF SCIENTIFIC RATIONALIZATION

by PROFESSOR H. LEVY, D.SC., F.R.S.E.

In the present address I propose to examine the evolutionary trend of the ideas that lie at the foundations of the subject of mechanism in order that we may if possible the more readily understand the functioning of the universe in which we find ourselves; for the subject of mechanics is not merely the study of machine construction, important as that may be for our material comforts. It is the study of the underlying principles of almost every branch of science as we envisage science at the present moment. It has become embedded in the whole structure of what we understand by scientific explanation. We are not satisfied—I use the word advisedly—with a description of a course of events until we have fitted it into a mechanical scheme. For a very good reason is it called "rational mechanics."

To the ordinary man, the universe around us is far from appearing rational and schematic. In most respects it is a medley of chance and chaos. A bird sings, a leaf rustles, a distant motor-horn hoots, a light appears and disappears in the house opposite. Into what scheme of organized knowledge could such discrete and apparently unconnected events be fitted? What possible principle could even be tentatively suggested?

I stretch forward my hand and grasp something that seems hard to the touch. We call it wood. I take a piece, make a series of marks on it, and use it as a standard measuring rod. I measure the length of this desk—it is 24·45 units. I verify by applying the measure once more. It is 24·47 units! I measure it again, 24·46 this time. Has it a definite length, and if so which is it? Does its length vary each time I measure it? I try again, and yet again, and presently I have a whole series of measures ranging from 24·43 to 24·49, several of them appearing many times. Which of these is the length—the true length of the desk? And here you and I begin to differ. You may say the

true length is something other than all these, each of which is vitiated by *error*. I, on the other hand, have not yet discovered that there is a unique measure to be attached to the desk, that there is a *true length* at all. All the evidence in fact is against it. Have I not measured it and found it to vary? You have begun with an *a priori* conception of length, and truth in relation to length, that I have not shared, and you have proceeded to examine the universe on the assumption that these concepts can be validly applied. They may not. You have been compelled to invent "error" to explain your differences. On the other hand, I have been content to take the universe as I find it. In the case of the desk the result of applying the measure to it was to give me a whole set of numbers. These are the measures that specify its length, and it is not a unique number. No matter, for so far I have not presupposed that the desk (or the measuring rod) possesses a uniqueness for which rigorously I had no evidence. But now I will make an assumption. Let us examine the measures we have obtained for this desk. Some have been found much more frequently than others. To each we may attach a frequency; for example, we may find that 24·46 has been obtained ten times more frequently than either 24·43 or 24·49, the two extreme measures. The assumption I will make is that 24·46 is ten times *as probable* as 24·43 or 24·49, in the sense that if anyone proposes to measure the desk it is ten times more probable he will obtain 24·46 than 24·43. He may find 24·43 but it is very improbable. I will assume, in fact, that after a large number of measures have been taken, the relative frequency will be unimpaired by further measures, and I use this assumption to assign a probability to what the next observer may find. The odds, in fact, are ten to one that to him the length will be 24·46 rather than 24·43.

The function of science is in the first instance to describe the universe as it is experienced; not as it is found convenient to describe it. Every term which is used in the description must then correspond to an operation that can be performed. In the second place it purposes to provide a means of prediction —a means for prophesying in advance the measure of the

experiences that must be obtained in certain presupposed circumstances. Even from the simple case I have selected for illustration, it is evident how complicated we may expect the problem to be.

This is, of course, all very sophisticated. Man has not arrived even at this comparatively simple concept of length without a severe struggle through darkness and error. The whole range of space and of time is his study, and his ambitions are nothing less than to develop, out of the medley of confused events in this immense field, a new sense of sight—the sight into the future, the power of prediction. If science does not provide this, it provides nothing. How immense then is this task? To gain some glimmering of the spatial aspect of the problem let us suppose the fastest aeroplane, with its speed approaching 400 miles per hour, has been chartered, and let us beat the frontiers of our space. At this speed the globe is circled in 2½ days, in three weeks we reach the moon, and the sun in twenty-six years. After 1,500 years has elapsed the outpost planet of the solar system would be at hand, and then a long dreary journey of 13 million years to a neighbouring star. After 90,000 million years, when it has passed beyond the Milky Way and reached the outer confines of our galaxy, the exploration of the universe proper would commence. This snail's pace is clearly too slow. Let us charter the swiftest messenger, a ray of sunlight, travelling at the incredible pace of 186,000 miles per second. We career around the earth in one-seventh of a second. In one-and-two-third seconds we have passed the moon, in eight-and-two-fifth minutes the sun is left behind, and after four years of this extravagant speed the first neighbouring star looms large ahead. Even so it is not until 100,000 years of journeying have been completed that we reach the outermost limits of the Milky Way, the frontiers of our galaxy. And now begins the million-year journey across starless space until the next galaxy of many million stars begins to approach. This, then, is the scale, in the large, that science has to handle. Events of this magnitude it proposes to describe by inventing laws, which man in his innocence terms the Laws of Nature.

How does man himself compare in size with one of these

lonely inhabitants of stellar space? To balance a star, if the weighing could be performed, there would be required in the opposite scale ten thousand million million million million (10^{28}) men. If every one who had ever lived since the dawn of man were replaced by as many individuals as had ever lived there still would scarcely be sufficient.

But puny as he is in the case of these immensities the scientist is yet arrogant enough to sweep within his field an almost equally difficult task, at the other end of the scale, the interplay of molecules within matter, of atoms within molecules and of electrons within the atom. It is indeed difficult to give any but the vaguest conception of the indefinitely small into which man has set himself to probe. He is himself composed of approximately a thousand million million million million (10^{27}) atoms. The atom, in fact, bears to him almost exactly the proportion that he bears to a star in the scale of weight.

What is the scale of time? Astronomers estimate the age of stars to be of the order of 10 million million years. The age of man on earth is at least half a million years. The lifetime of an individual, three score and ten, of certain insects a day, a stop watch can measure one-fifth of a second, an electric discharge is of the order of one-millionth of a second, but the movements of the electron in the atom take place—if these notions of time and speed have any significance—in one-hundred millionth of a second or less.

Who is man and what is his experience that he should expect to be successful in framing a description of natural events that should be valid from the one end of this vast scale to the other, spatial, temporal and material? After all, the experience of mankind is limited both in time and space. Man has played his part within a few feet of the surface of a tiny globe in the sky, with an ancestry that dragged out the greater part of its life in mud and slime. 500,000 years ago he was a wandering savage and for at most one per cent. of that time has he been in any modern sense civilized. It was but yesterday that he crawled from his cave and peeped fearfully at the world in which he found himself. His mind is steeped in vain fancies, vague terrors, unconscious and unexpressed assumptions.

Knowing him as we do, a child of ignorance and an inheritor of falsehood, we recognize his folly in daring to frame unrestricted laws for this immense universe in a language expressive only of his narrow cave experience. His tiny circle of knowledge has set a bound to his powers of thought, and what is cogency in his logic must be little more than cramped imagination. On such uncertain foundations do we build the majestic Laws of Nature. One has merely to skim the pages of the history of accurate knowledge to recognize the dangers of dogmatism.

With such a background, what significance can we attach to accurate knowledge, to certainty? If in no other respect, Man differs from all other beings at least in the behaviour of his tongue, the capacity for speech. But there is speech personal and speech impersonal, private and public. There is the warning cry that indicates a bear has entered the cave, and there is the tone or pitch of the cry which is evidence of the state of fear of the individual. The public or impersonal element is that which refers to the bear's entry. It is an event in which all participate; we shall call it public knowledge. It may have a private component, it may ultimately be entirely personal—I am not dogmatic. It is through the public or impersonal aspect of speech description, however, that physical science has developed. So-called private feelings play no direct part in its make-up. But even if the pursuit of science be limited to this field of public behaviour, be it the distance, action, and composition of the stars, the nature of time and space, of the marine and atmospheric tides, the stirring of a leaf, the rippling of water, the flexure of a muscle, the nature of cell structure, the behaviour of animals and of human beings, in what sense can we talk of truth and certainty when we recognize that ultimately assent and judgment must be won from us, who are so near to the animal that fancy and illusion may pass for accuracy?

In the face of this science has proceeded in the only practicable way. Every public scientific statement, general or particular, regarding the nature of the universe is subject to confirmation by experiment or prediction. Experimental test is a gauge

through which every aspect of the public or rational picture of the universe must pass. I make no distinction in this connection between *public* and *rational*; for just as our public conception of the universe around us has evolved and expanaed, so has our conception of what is or is not rational evolved in our passage from savagery to civilization.

But there is a corrollary to the principle of experimental verification that follows, if it is to be rigorously applied. The statements of public fact, whether in detailed form or as grand generalizations that we dare to term Laws of Nature, must be expressed in terms themselves capable of experimental definition. Although I cannot elaborate this here, it appears to me to be a fundamental of scientific method, and, if ignored, allows such statements as "Nature abhors a vacuum" to pass as scientific descriptions. It is in effect the distinction between personal and impersonal description.

From the point of view we are here developing Truth and Reality, as all else, have a significance only in relation to the epoch. They are evolutionary concepts expanding as the certainty of our knowledge expands. There can be no scientific absolutes. If we have other interpretations to these words do not let us thereby confuse our thoughts by confusing our diction. They cannot refer to their scientific interpretation without the relevant experimental proof.

The history of science is a tale of the gradual evolution of a language of description and of a delimitation of the scope of certainty in statement and experience. It is a story of trial and error; the tide of knowledge has flowed and ebbed, discoveries made, forgotten, and remade. The beginnings of certainty made their appearance as soon as it was seen that natural phenomena were capable of numerical treatment. Probably to Pythagoras, and later to his disciple Plato, must be given the credit for first recognizing this vital fact; for it implied that the exact methods of mathematics which had developed almost independently, as opposed to formal definitions and verbal arguments, could be turned to a discussion of the physical world.

Of the greatest moment was the application of Geometry

to the determination of the figure of the earth, and finally of its measure. It was a revolutionary step, the first effort towards a rational conception of the world. It was in a sense one of the first attempts to examine whether a purely mathematical series of propositions had a useful relevance to physical fact. But its implications in this respect were not realized. It was the mathematical geometry that was regarded as fundamental and perfect, the shape of the earth a mere physical approximation to the true reality of geometry. Had the stress been on the physical fact, and a geometry sought that would represent its numerical and structural aspect, the history of scientific discovery might have been otherwise. The needs of the age were not conducive to the development of such a standpoint. Mankind had not yet emerged from a belief in the mystical properties of numbers and geometrical figures, and as we shall see, many centuries had to elapse before the first glimmerings of freedom showed themselves. Tools, and elementary mechanical contrivances, were evolving in the struggle for existence and comfort, from hammer to sailing ship, but no system of rational mechanics either in reference to the mundane facts of life or in reference to the world cosmos, made itself apparent until the darkness of the middle ages had all but passed.

Then came one of the greatest deliberate experimental tests of any mathematical theory in history, the quest of Columbus. The discovery of America came to the New World like a bolt from the blue, yet the voyage of Columbus was a deliberately prepared experiment undertaken to test a definite theory. Measurements had been undertaken, a wealth of fact and theory had been examined, tremendous inductions had been constructed. The theory was put to the test of experiment. The scientific method, the rational use of experience, of hypothesis, and of verification had won its first brilliant victory and the march of science had begun at last. The thoughts of men were searching critically to the place of mankind, and the place of the earth, in the world of stars and planets. The search had begun by an examination of the planet on which he stood.

Hardly less significant for progress than the discovery of

the New World was the invention of the printing press in the fifteenth century. It is difficult for us who suffer from a surfeit of the printed word to realize now what the intellectual state of the world was before that great event. The works of the Polish savant Copernicus, working at that time in Frauenberg, were *printed*, and the Copernican system was saved from the fate of his forerunner, Aristarchus in Alexandria, by the mere fact of its dissemination throughout the thinking world.

Between 1470 and 1500 more than ten thousand editions of books and pamphlets were printed, and the discoveries of Columbus and of Vasco da Gama were soon the common property of Europe. The habit of books, the habit of reading, was spreading fast, and of the numerous revolutions that had started against the ascendancy of the Church, it was that of Luther in the second decade of the new century that fell on prepared soil. The weapon that forged the success of the Reformation was undoubtedly the printing machine.

On such soil and into such an atmosphere was born the *De Revolutionibus* of Copernicus in about 1540. A Roman Catholic priest in an obscure corner of Poland, he produced a volume that was destined to effect a greater revolution in the thoughts of men than any single volume before or since. With the sophistication born of nearly four more centuries we find it difficult to think our thoughts into these days. He who would assert the permanence and rigour of logic as timeless, perfect, and indestructible, should read the *De Revolutionibus*. We must bear in mind that astronomy and astrology had not yet parted company, a divorce that has not been completely achieved even in our day. Thus in effect Copernicus argues that the earth must be round because a sphere is the most perfect form—reminiscent of Aristotle and the ancients. It is for like reason evident, he points out, that the heavenly bodies are spherical, just like drops of water, and the heavens too must be spherical. The earth *circles* round the sun, the circle being the most perfect curve. He saw that if the earth in its motion did not hold always to exactly the same tilt, that if its axis swayed ever so little this would produce precisely the effect known as the precession of the equinoxes, and so on. These,

to us, now elementary propositions were nevertheless of vital import for the future.

In gauging the importance of this work we must remember that Copernicus had no telescopes with which to search for verification of these ideas or to suggest them to him. Unlike his forerunner Aristarchus he was no student of a brilliant school at Alexandria of astronomers, thinkers, and philosophers, but a lonely worker in a far corner of Poland, who evolved a system that dethroned the earth from its position as the centre of the world. To Copernicus must be given the credit I think for inventing the simplest geometry of the mechanical solar processes, for his was essentially a geometry. It borrowed little if anything from physical science. It was a direct mathematical effort. There was little in the social or intellectual atmosphere of the time to suggest mechanism to him at all, and he was content to regard it as a problem requiring merely geometrical description. The why and the wherefore of it were wrapped in the mysteries of nature. Machines of any sort were almost wholly lacking in his day. Man could hardly construct a mechanical theory of the solar system before he had appreciated the necessity for a mechanical description of the more mundane facts of life. In the light of the development that has taken place since those days it is certainly worth while noting that with the absence of all mechanical notions from the Copernican system went also no mention of forces gravitational or otherwise, and an almost complete absence of the notion of cause and effect. There was no problem of determinism in the modern sense.

The book was a bombshell, but few heard it explode. Seventy-five years later the Church awoke to realize that here was a work that threatened established belief, and so in the end it was banned. The new leaven worked slowly. The greatest scientific figure in Europe, Tycho Brahe, whose accurate astronomical observations were to provide the stepping-stones for Kepler, disavowed it. Luther denounced it on scriptural grounds. "Does not the sacred Scripture tell us that Joshua commanded the *sun* to stand still, not the *earth*." Leonardo da Vinci, almost the most versatile genius who ever lived,

pioneer of science in all directions, passed it unheeded. Among scientists proper, if such who necessarily possessed the somewhat medieval mind of the age could be so called, Kepler, still a boy, alone accepted the new position unquestioningly. But just as Darwin had his Huxley, so Copernicus had his Bruno, the inventor of the first scientific religion, the propagandist of the new ideas. In the end he paid his penalty at the stake, but not before he had carried the new abstraction of the heavenly bodies to the rapidly growing intellectual centres of Europe.

Towards the close of the sixteenth century, in the early days of Shakespeare and Bacon, young Johann Kepler, a sickly lad who had graduated from potboy to student, was eagerly absorbing the new Copernican vision of a geometrical universe. No better insight could be gained into the mental atmosphere of the age than by a study of the problems of the young Kepler and what he regarded as the most satisfying solution. Six planets, and six planets only were known. Why six? Why six? If Copernicus is right, what keeps the planets moving? Here for the first time there obtrudes into the question the notion of cause. And why six? At last he makes what he conceives is a great discovery. There are, of course, just five gaps between the six planets. It is known that there are just five regular geometrical solids, solids whose faces have all the same shape. Geometry is the most perfect field of knowledge, Nature is necessarily perfect. Hence there must be a gap between each pair of planets for each regular solid! His idea is in thorough keeping with the time. It is a survival of the old Pythagorean mysticism of numbers. In the cold light of 300 years' further experience it sounds incredible to us that this could be other than the ravings of a maniac; I will not tarry to press the moral that logical conviction and the sense of the obvious are themselves evolutionary. We have merely to note the fact as a temper to undue optimism and vigorous dogmatism in our own time.

Full of his theories, Kepler journeys to see Tycho Brahe, the greatest astronomical observer of his time, and the inventor of a telescope, and they discuss matters. Brahe is no Copernican. He is the first thorough-going experimentalist. He sticks to his

observations, and the facts dictate that the planets do not move in circles. Time was when a fact had no standing beside a theory, but to Brahe, the true forerunner of observational science, astronomical facts were paramount. For eight long years Kepler figures and struggles with these data, and at last he stumbles on the solution.

Kepler's three laws of planetary motion, produced by him almost in a state of religious frenzy, provided the basis for a logical description of the motions of the heavenly bodies.

In the first place he announced that a line joining the sun to any planet during the motion of the latter sweeps out equal areas in equal times. It was, be it noticed, a geometrical law, a kinematic description, a statement of lines and areas in motion. Secondly, the orbits of the planets were ellipses, again a geometrical statement. This was in 1609. Nine years later came the third law, announced in an exultant paean. It showed that the enormous mass of data that had been accumulated on the motion of planets could be summed up under one guiding law—the cube of the distance of the planet from the sun is proportional to the square of the time of revolution—or, stated otherwise, the product of the distance into the square of the speed is the same for every planet.

It is almost impossible to overestimate the extraordinary *tour de force* that the formulation of these laws represented. Here was a man completely ignorant of all but the most elementary weapons of mathematical analysis, faced with an appalling mass of diverse and not too accurate astronomical data, with a mind still held by medieval bonds, and from this welter of disorder, from a region still regarded as subject to the mystery and caprice of the gods, he extracts simplicity, mathematical predictability, law, and order. It is an amazing performance. Just as Copernicus provided for him the broad geometrical abstraction of the physical problem that enabled him to describe its numerical aspect in these simple laws, so he placed in the hands of Newton, his successor, the detailed geometrical forms of these abstractions from which were to arise the so-called law of universal planetary attraction—the law of gravitation. Kepler himself came near to divining this

and even Copernicus vaguely hinted at some such characteristic. In his introduction to his 1609 laws Kepler points out, in language that sounds quaint to our ears, that every natural substance by nature remains in repose when it is isolated and outside the sphere of activity of bodies which have an affinity for it. Gravitation, he says, is an affection or quality with which bodies are endowed in order to hold them together; and so on. In spite of the animistic concepts of Kepler whereby he endows his bodies with a personal urge that keeps them on their masterly way, he is here not far from anticipating Newton. We have to remember that while Kepler was vainly searching for causes, reasons, effects, no science of mechanics existed. It is, I should think, fair to say that this want, supplied by Galileo in time to be placed in Newton's hands, robbed Kepler of the final honour of reducing all known planetary motion to a single principle—the law of gravitation.

Kepler died, as he passed his life, in bitter and abject poverty.

The first page of the history of modern mechanical civilization was written by Galileo. A contemporary with Kepler, a student of medicine, he concentrated his attention as a youth on the human machine and, among other matters, on the apparent regularity of the pulse beat. On his knees one day in the Cathedral, his thoughtful eyes follow the swing of a great lamp which the verger has just lit. Though its path of motion grows steadily less, the duration of its swing remains unchanged. By such a chance is the principle of the pendulum, known indeed to the Arabs, but since forgotten, discovered anew; but more important still the mechanical curiosity of a great mind is excited. He will examine the things around him with an unprejudiced eye stripped of the foolish unverified dogmas of the ancients. His rediscovery of the pendulum laid the foundations of a new branch of science—dynamics, the study of bodies in motion. He challenges the ancient belief that heavier bodies fall faster than light ones: and he proves it—not to be noted by appeal to logic and disputation, we have seen how treacherous a support that may be—but to the physical logic of experiment. He has discovered the uniform acceleration of gravity.

"I should certainly venture to publish my speculations,"

he writes to Kepler, "if there were more people like you. . . . I refrain from such an undertaking so great are the number of fools." We have to remember that very soon after, Bruno, a champion of these views, is taken to Rome in chains and burnt at the stake.

Galileo builds a telescope, a mighty one in these days, and he enlarges the scope of the heavens a thousandfold. The broad outline of the Copernican theory and Kepler's laws are verified up to the hilt. Rome steps in. The work of Galileo and of Copernicus are placed on the Index and he is under orders to refrain from teaching or believing in the motion of the earth. The power of the Church is used to crush the new heresy. This, in 1616, the year of Shakespeare's death. There is no need to recount the story of the later writing of his *Dialogues on the Ptolemaic or Copernican systems*, or the storm it aroused, of his second summons to Rome, of the infamous treatment of a great scholar of seventy by a mighty, tyrannous, but ignorant Church, and of his final recantation. The greatest mind in Europe returned broken in body and spirit—a mental prisoner; but his work survived. The year that saw the end of Galileo saw the birth of his successor. Kepler and Galileo between them had erected the framework which was to support the mighty structure of Newton.

Of Newton's work it is impossible to speak in the short space at my disposal. Even a mere catalogue of his achievements would fill up most of this lecture. Gravitational force, an animistic conception, was already recognized and accepted without the criticism which it has received in modern times. True, Newton himself was not quite happy about the whole concept of force that he did so much to rationalize. In his *Principia*, the law of gravitation and the statement of its measure is put forward merely as an hypothesis in a great mathematical scheme. What is important to us here is that with the aid of this principle and the mathematical weapons which he himself devised he described the planetary and solar system as one vast piece of mechanism. He reduced the description of their behaviour—their past behaviour—to a set of mathematical equations; philosophically the remarkable thing was that the

future behaviour of that system fitted in as closely as could be gauged at that time into the same equations. The mathematical determinism of his equations, in fact, corresponded to a capacity for prediction in physical phenomena that was all but lacking hitherto. And the methods he developed combined with his statement of the laws of motion—laws whose formulation as we have seen owed much to Galileo—were the foundations on which have been built the whole of modern mechanics and machine construction. It is not easy now to realize the vast forward stride which the publication of this work represented; it is equally difficult to separate out what was wholly Newton's own. The *Principia* is primarily a book on mathematics—the geometry of motion, replete with diagrams, in the style and language of Euclid, proposition succeeding proposition in a logical chain. Were it not for the presence of so-called physical concepts such as mass and force it might be regarded as a piece of pure mathematics. Newton's first law stated that every body continues in a state of rest or of uniform motion in a straight line except in so far as it is acted on by force. This is stated as an hypothesis, without experimental evidence. Taking the law bluntly as it stands, various criticisms of a more or less fundamental nature have been raised against it. It assumes the notion of force in an indirect way by nominally providing a means of discovering when it is absent, from an examination of the motion of the body concerned. If the body is at rest or moving in a straight line there is no force acting. But how is one to discover whether a body is *at rest*? What experimental meaning has the term? Rest is a relative term, rest in this room, rest with reference to the earth, the sun, the stars. . . . For some considerable time the significance of this criticism was pushed into the background by *assuming* a fictitious *fixed* ether. *Ad hoc* assumptions of this nature without experimental evidence get us nowhere. The criticism with regard to *rest* applies also to straight-line motion. A ball dropping in a straight line on to the moon, i.e. when seen as a straight-line motion from the moon, will be seen as anything but a straight line from the earth for the ball will partake of the moon's motion. Are we to start with the notion of force then, and be

compelled to give it a different interpretation when we are sitting in our armchair, walking in the street, travelling in a tram, rising in a lift, or journeying on the moon? Such difficulties with regard to the first law apply equally to the second.

When a body is moving with accelerated speed the force which acts on it is measured by the product of the mass of the body into acceleration. I will not weary you with the objections that have been raised to this. At the best, even if acceleration were an absolute measure and not relative like *speed* and *rest*, this would merely provide us with a measure of a single quantity the ratio of the force to the mass of the body. Difficulties such as these have driven mathematicians to seek a formulation of the laws of mechanics which is independent of, or invariant to, the position and motion of the particular observer. The laws as they stand, it is argued, are personal, not impersonal laws; one does not observe an impersonal localized force, but merely matter in displacement. The laws must be independent of the particular frame of reference of the observer. The experimentally observed fact of the constancy of the velocity of light in all circumstances, whether the earth is moving towards the source or away from it, enabled Einstein so to readjust our conceptions of time and space as to effect this. They became, then, geometrical laws solely. I am not here concerned with this development. What I want, however, particularly to direct to your attention is the fact that the laws as they stand were assumed by Newton as hypotheses—assumptions in a mathematical chain. The terms in which they are expressed are not experimentally definable or determinate, as we have seen. The physical operation for discovering whether the body is *at rest* in any absolute sense cannot be performed nor would we recognize a force if we saw it.

How is it then that laws which are as specialized as those of Newton appear to be, and contain animistic conceptions like force, have been so conspicuously successful? The fact is that in their application to idealized problems drawn from nature, the force concept acts merely as a sort of liaison officer. It is a mere intermediary that falls out of the calculations.

We take a certain body and note that it falls to earth with an acceleration of 32 feet per second per second. We hang the body on a spring balance and the spring extends. If the body and spring now move along a smooth surface at such an accelerated speed that the extension of the spring is exactly that obtained before, it will be found that the acceleration of the body is 32 feet per second per second. Newton's Law tells us that if two such bodies joined together were moved in this way so that the extension were still the same as before, the acceleration would be one-half of 32 feet per second per second. Hooke's Law, on the other hand, discovered about the same time, if used in conjunction with Newton's Law, would tell us that if only one body were moving in this way at an acceleration of 16 feet per second per second the extension would be just half that previously found. You will notice that the notion of force is completely absent from this description; everything can be described in terms of motion and mass, and with its absence has gone the seeming urge for describing this personal conception of force as a "cause" of the motion or the necessity for explaining that the motion is the "effect" of a force. Nevertheless, in Newton's description of these laws the notion of force was definitely interwoven, and with it there has easily slipped in extraneous questions associated with the use of the terms *cause* and *effect* and the causal notion of determinism. It is true that when the equations are used in the manner in which I have indicated, the measure of the motion sought for is uniquely determined. This is, of course, mathematical or logical determinism and, interlocking with the previous extraneous notion of force which dragged "cause" and "effect" in its train, there appeared a cast-iron case for a mechanical universe such as had its greatest vogue in the Victorian age.

The Newtonian system appeared then to give a clear machine-like picture of the universe as an engineer would envisage it. It was set in a realistic mould of space and time with mass and gravitational force, corresponding with what has become —*become* be it noted—a common-sense view; a clockwork universe in effect, of wheels and springs, but maintained by

a mysterious causation. Newton, himself a fundamentally religious man, was thus the creator of the first scientific system of the age of mechanism where, to him, God acted as the great Engineer controlling the machine and maintaining the even passage of space and time. Unlike his forerunners the publication of this great work brought its author neither to the prison chamber nor to the stake. On the contrary he was granted a Government post at a then princely salary of £1,500 per year; for England, intellectually, was one of the freest countries in Europe. Yet in a sense the work of Newton was far more irreligious, or at least it undermined orthodox dogma to a much greater extent, than the work of Galileo. Leibniz, Newton's contemporary, and a co-discoverer of the differential calculus, declared that Newton had robbed the Deity of some of his most excellent attributes, and had sapped the foundations of Natural Religion. Its reaction on English theology was significant. A Cambridge divine translated the *Principia* from its Latin into English, and there gradually arose in the Church a school of thought which sought to incorporate the new science by establishing a theology based on the new mechanistic conception of the universe.

The years that followed the work of Galileo on the Continent, and the period of Newton in this country, saw a great expansion in mechanical knowledge. Harvey discovered the mechanical action of the blood, the action of the suction pump was elucidated. Torricelli invented the barometer and the whole field of hydrostatic pressure was laid open. Boyle and Marriotte discovered the laws of gas pressure that were shortly to play such an important part in compression engines, accurate thermometers began to be made. In 1628 Lord Somerset, Earl of Worcester, had a rude contrivance for raising water at Vauxhall. In 1666 he had taken out the first patent for a steam engine. Huyghens, in 1657, patented a clock which for the first time, or a little later under the influence of Hooke, combined the principle of the escapement with that of the pendulum. In 1662 the Royal Society was founded and a focus of scientific interest was brought into being in England.

It would be pointless for our purpose to detail the numerous

mechanical contrivances, great and small, that have seen the light of day since that period, but it is important that we should recognize the great process that has been at work. Newton had laid down in his laws of motion an apparently precise measure of force in terms of the behaviour of the mass acted upon by it, irrespective of the nature or origin of that force. But in effect, without stating so explicitly, he had commenced a revolution of a different kind. He had popularized what may be called the principle of abstraction. The earth was an enormous mass of non-homogeneous material, rocks and clay, seas and forests, mountains, hills, and valleys. Its path round the sun was evidently not a curve, but a huge band in space 8,000 miles across (the diameter of the earth). He banished the earth, its mountains and seas, the huge band representing its track. He eliminated the immense mass of flaming gas that was the sun. He ignored its heat, and he replaced this whole complicated panorama of nature by two pure geometrical points, one moving round the other but attracted to it by an idealized force which acted along the straight line joining the two points. From the enormously complicated problem that nature presented to him he abstracted, he invented, a pure geometrical combination of ideal points and lines plus an abstraction-force. The importance of this step lay not merely in what he conjured up but in what he dismissed as irrelevant for the purpose he had in view.

It is essential to recognize the implications of this extraordinary simplification that he had introduced into an exceedingly complex phenomenon, for it gives the key to practically all the later developments in mechanics, and incidentally to a great deal of mystification that has crept in of later years. It meant that as soon as it became clear and definite how the forces in any problem were brought into play, by a similar process of abstraction that problem also could be dealt with. If we know how water resistance depends on the speed and shape of a boat, the motion of the boat in any circumstances can immediately be predicted. If we know how the air resistance of a shell depends on its speed, by a similar process of abstraction we can prophesy exactly what is the

range of flight, and so on. What we have to grasp is that the Newtonian method apparently made it possible henceforth to deal with the measurable aspect, the magnitude of the forces, masses, and motions, of any physical, chemical, or physiological problem. The future history of mechanical invention and of scientific application became from this point of view the utilization of the physical or chemical forces exposed by any new investigation towards the movement of a machine. This is true whether the process be electrical as in the case of the motor generator or the electric tramway, chemical as in the case of the internal combustion engine or the use of coal power, or physical as in the case of the airplane propellor. Under the impact of this weapon, the face of the world has been altered. Green fields have been transformed into networks of railways, and steaming monsters rush across country at seventy miles per hour. The machine age has changed agricultural into luxury-producing nations herded together in slums. Our cities are tunnelled for underground electrical transport, and aerial machines scream past us at the incredible speed of nearly 400 miles per hour. Silent dreamy villages are transformed into buzzing cities, giant cranes rear their necks into the skies, and pneumatic drills cut their way through the rock. Tulips that yesterday were nodding their heads in the fields of Holland are to-day being sold in the streets of London, Paris, and Berlin. Even the very thoughts of men have been duplicated by the machine. Bank tellers and clerks are ousted by the mechanical calculator which adds, subtracts, multiplies, divides, even takes square roots, differentiates and integrates, adds up and prints money totals and subtotals, and enters your bank overdraft in red ink. The enormous quinquennial census and the multitude of classifications it involves are effected by this mechanical brain. It is estimated that during this past five years, 200,000 computing machines have come into use in this country alone, involving at least an equal number of unemployed. Science and its mechanical principles have revolutionized production and destruction, and the social structure is thrown out of gear.

The ordinary conception of science is that it reveals the

world as a closed and complete system in which all entities are predetermined. This view, whatever its validity, is certainly fostered by the usual method of scientific exposition which gives us the picture of science completed rather than science evolving. We have to bear in mind simultaneously that being a human construction of comparatively recent growth, science is in that measure a characteristic of human beings and therefore falls under the subject heading of Human Biology—one of its own parts; while man being a mere physical entity in a larger universe must—with all his characteristics—be regarded as a subject of physical study. Whether we regard physical science from the biological standpoint, or biological man from the physical standpoint, we are presented always with the same picture—the story of the gradual evolution of scientific certainty from primitive darkness, and with it, and of it, the rise from primitive man. If history then can teach us anything it teaches us to beware of undue dogmatism; to avoid assuming that finality has been attained in any way, even in the most trivial aspect of the picture man tentatively sketches of the universe around him. On the other hand science is the only type of knowledge mankind has achieved so far that can have any claim whatsoever to be regarded simultaneously as physically precise and rationally organized. The creation of individuals and of peoples, its results are yet available to all. Races that have not shared the culture of the West may yet share its scientific knowledge, adapt it to their own social and cultural needs, and contribute towards its further advance. It stands above social and religious divisions, and it turns a flood of light upon them. So far as the world is understood by us, the immediate portion in which we live our lives is describable, as regards its past at least, in terms of its machine-like characteristics so orderly and exactly, that we are induced to predict its future with the certitude that we gauge that of a wheel or a top. While thus analysing cosmos in terms of mechanistic concepts, and thereby resolving its intricacies, man yet pursues his course as if human actions were almost entirely under human control. He may accept the mechanical necessity of processes in the outer world, but the recognition of his more

intimate personal phenomena, his private world, as a mechanistic process still eludes him.

A scientific system uncovers truths that are objective in the sense that they are independent of individual human preferences and aesthetic desires. But while the truths are accepted as they are found, and fitted in tentatively into a rational and logical description of the universe, we cannot avoid inquiring to what extent the order and relation in which they are placed depends in any way on the human make-up and how far on a physical structure of the universe. It is easy to raise questions of this nature; it is more difficult to discern whether these questions have a sensible meaning for us, whether in fact there is a physically definite answer to balance the question. Here for the moment we will leave it. We know too little of the human brain and its functioning even to discern whether or not we are asking childish questions.

BOTANY

by SIR ARTHUR W. HILL, K.C.M.G., SC.D., F.R.S.

BOTANY is now so large a subject, with so many ramifications, that I do not think you will expect me—even if I had the power—to address you on the modern aspects of Botany in its many different branches. Botany to-day includes systematic and economic botany, mycology—that is, the study of fungi—plant breeding and plant physiology, ecology, etc., while it also has close relations with chemistry, medicine, and soil problems. So that the subject is much too vast to attempt to deal with it as a whole in the course of a single lecture.

As the work which the Royal Botanic Gardens, Kew, attempts to perform for the Empire lies mainly in the direction of Systematic and Economic Botany, I hope it may be of interest to you if I say something about the modern developments in these two branches of our science. Systematic Botany is the side of the science which relates to the accurate naming of plants. In order to obtain an exact knowledge of the plants of the world it is necessary to be able to distinguish one from another by means of carefully compiled descriptions, which entail detailed and critical examination. We are thus enabled to classify the plants into their related groups, and study the allied plants which come from different parts of the world. This careful examination is not only important from the point of view of pure botany, in the endeavour to obtain a comprehensive knowledge of the vegetation of the world, but it is of particular importance in the case of all plants which may be of economic value—that is, plants on which we depend for the various commodities which are derived from the vegetable kingdom.

The careful descriptive work which is entailed in systematic botanical studies necessitates the preparation of detailed floras of the different parts of the world, and at Kew, which is the headquarters of botanical work for the Empire, it is our main aim and object to deal critically with the plants which are native

in our several Dominions and Colonies. From Kew, therefore, have been prepared the various colonial floras, and among the more important works, running into many volumes, which have emanated from Kew may be mentioned *The Flora of British India*, *The Flora of Australia*, *The Flora Capensis*, *The Flora of Tropical Africa*, and several other colonial floras. We are now engaged on a "Flora of West Tropical Africa," part of which has been published, and it is proving of great value to all whose work is associated with the vegetable products of our West African colonies. The Herbarium and Library at Kew is the place where this work is being carried on—and our Herbarium is very well equipped for the purpose, since it now contains about four million dried specimens representative of the vegetation of the world, and our Library is probably the most complete botanical library in existence.

Systematic Botany has been undergoing many changes during the past few years. In early days, when Linnaeus carried out his monumental work, there did not seem to be many problems as to what exactly a species might be. Now, however, with a closer and more intensive study of plants we find that among plants hitherto regarded as the same species, many varietal forms can be found, either coming from different regions or from different altitudes, and it is also found that the different varieties or races tend to breed true to their special characteristics. In the case of plants which have no particular value from the economic point of view, these small differences are mainly of scientific interest; but in cases where the plants yield some important economic products, the small varietal differences are of very great importance, since it is found that in some cases a particular variety may yield the desired product in large quantities, while in other varietal forms the product may either be present in small quantities or may not occur at all.

The realization of physiological and morphological varieties in what has hitherto been regarded as a single species was very strongly brought to my notice during my stay at Pretoria, during my recent visit to the Union of South Africa. There, have been collected together the different varietal forms of the woolly finger grass, *Digitaria eriantha* Stend., which are native in

the Transvaal and the neighbouring parts of South Africa, and Dr. Pole Evans has in cultivation at Pretoria some eighty-five distinct forms of this species. When I saw these plants, which had all been reproduced from the wild-collected plants, they were in many different stages of growth. Some were in flower, some were brown and had died down, some produced long, creeping stolons on the surface of the ground, while others had similar stolons which were below the surface of the ground; some again, had green leaves and in others the leaves were of a bluish-green tinge. It seemed quite clear that a large number of micro-species—as they might be called—were represented in this collection of forms of the woolly finger grass, and it was very striking to see them all brought together in adjoining plots. It was all the more striking as, though there had been no rain for some six months, many of the forms were as green and fresh as if they had recently received water.

Dr. G. Turesson, working in Sweden, who is well known for his work on ecological botany, has recently prepared an important paper on the selective effect of climate on the plant species. He has studied plants collected in different localities and from different climates in Italy, Austria, Germany, Asia, Scotland, and Sweden, and has grown them under controlled conditions side by side in Sweden. As a result of his researches he finds that our recognized species can be differentiated into ecotypes, and taking the two criteria "height of growth" and "earliness" into consideration, he finds that finite groups of biotypes within a species can be distinguished which belong to definite areas. These lines of ecological research in connection with wild species cannot fail to lead to important results in the fields both of Agriculture and Forestry.

Similar work with trees has been done at Les Barres in France, and there Scots Pines may be seen which have been raised from seed collected from very different localities, which, after three generations, still preserve the characteristics of the trees peculiar to the areas from which they came. It appears, therefore, that within the Linnean species we must now recognize definite subspecies, or groups of biotypes, which have

become differentiated in some degree in the several and widely separated localities in which they occur in nature.

Following on the work of Turesson, and of some of the American workers in plant ecology, some important work is being done, under the auspices of Kew, at Potterne in Wiltshire, to test the effect of different soils on the same plant. Four large beds have been made and filled with four different types of soil, namely, sand, calcareous sand, clay, and calcareous clay, and a number of identical individuals of *Centaurea nemoralis* Jord., *Silene vulgaris* Garcke, *S. maritima* L., *Anthyllis vulneraria* L., *Plantago major* L., and *Fragaria vesca* L., have been planted in each of the beds. The most obvious changes, so far noticed, are taking place in *Silene vulgaris*, *S. maritima* and *Plantago major*; especially in the latter plant, as this has proved even within five months to be exceedingly plastic. The original plant was a dwarf form and this habit has been very nearly retained on the sand and to a less degree on calcareous sand, but on the other soils a marked deviation has been shown in the way of luxuriant growth, so that the plants on the two clay soils are quite different in appearance from those on the sands. The changes which have resulted with these six species on the different soils are being continued, and many interesting biological facts are being observed which emphasize the importance of carefully controlled work of this character in the domain of systematic botany.

Another more recently appreciated factor in connection with systematic botanical work has been the recognition of the part played by hybridization, and this has been very strikingly borne out by the work of Dr. Cockayne in New Zealand and Dr. Lotsy in South Africa. In New Zealand it has been found that a very large number of natural hybrids exist between species, and nearly three hundred clearly recognized hybrids have now been described between well-defined species. It is not only among shrubs and herbs, but also among the trees, such as *Nothofagus fusca* and *N. Menziesii* (Antarctic beeches), that these hybrids have been noticed; and it is now very difficult, without most careful and critical work, to recognize which may be hybrids and which pure species when working with

New Zealand plants. The value of the New Zealand work has been much enhanced by the definite proofs which have now been obtained of the existence and validity of the hybrids, since many have been artificially produced by the botanists in New Zealand, and the artificially produced hybrids have been found to be identical with those which occur in nature.

In South Africa there is very good evidence that some of the Aloes and Crassulas are definitely hybrids between two or more species, and very possibly some of the Euphorbias may also be hybrids; but the definite proof of the hybrid nature of some of the South African plants, hitherto regarded as species, will need considerable time, and a great deal of experimental work will be required before any artificially produced hybrids can be raised to the flowering condition.

The recognition of the occurrence of hybrids in nature is not confined to New Zealand and South Africa, but wherever the vegetation is being critically studied, evidence of the occurrence of natural hybrids is accumulating more and more. In our British flora there can be little doubt, I think, that many of the described "species" of the genus *Rubus*—that is, the blackberry in particular—may be of hybrid origin, and in the case of *Centaurea*, Knap-weeds, it has already been proved by experiments at Potterne, carried out by Mr. Marsden Jones and Dr. Turrill, that three or four species which have been described in this genus by British botanists are really natural hybrids. When we turn to the economic aspect of the case, the occurrence of hybrids may be a matter of considerable importance, and this is well illustrated in the case of New Zealand flax, *Phormium tenax* Fonst., the main source of the binder twine used in this and other countries. *P. tenax* is native to New Zealand, where it inhabits swampy ground, and there are one or two other species which also occur in the Dominion. It has now been realized that a vast number of natural hybrids occur between these different species of *Phormium*, and when an area of wild-growing *Phormium* is inspected, it can be seen that the plants vary considerably in the length and habit of their leaves. The fibre contained in the leaves also shows considerable variations; in some cases it is good for binder twine, in other cases

it may be too short or it may be insufficiently strong for the purpose. The economic botanist in New Zealand, therefore, is faced with the problem of selecting the best type of plant for yielding the highest quality of fibre, and it may be that the pure species, *P. tenax*, or possibly one of the hybrids, will be found to yield the best product. If it should prove to be a hybrid, then it will be necessary for the plant breeder to carry out experiments in order to produce the desired form in commercial quantities.

In speaking of hybrids and their importance, I may remind you that our Strawberry, which we grow in our gardens, is itself a hybrid of no small value, its two parents being *Fragaria chiloensis* from Chile, and *F. virginiana* from North America.

I referred earlier to the varietal differences shown by plants of the same species, and mentioned that these varietal differences are of considerable importance when they are found in plants of economic value. Para rubber, *Hevea brasiliensis*, is a good example. The rubber obtained from this plant, which is the source of all the india-rubber used for mackintoshes, motor-tyres, etc., occurs in the latex or milky juice which is yielded by this tree. It has been found in the plantations in the Federated Malay States and elsewhere that there are very great physiological differences between the different trees. One tree may yield as much as 40 per cent. of latex, whereas another tree, botanically quite similar, may yield not more than 2 or 3 per cent. of latex. Obviously the plantation furnished with high-yielding trees would be a far better proposition than one in which the trees yielded only a small percentage of latex. Physiological differences of this kind open out many problems to the botanist and agriculturist, since it becomes his business to try to propagate high-yielding trees, either by vegetative means or by carefully planned genetical experiments. Though we now have a great deal of information on which to work, thanks to the discoveries of Mendel, it is no easy matter to produce plants with the desired qualities without a very great deal of protracted research work.

Theobroma Cacao, the source of our cocoa and chocolate, also illustrates many of the difficult problems in the lines of

economic botany. So far as we know, the cultivated cocoa of commerce is a hybrid between two wild South American species, for the offspring varies very considerably, especially in the direction of heavy and light yielders of fruit. Here again, for success in plantations, it is essential to grow varieties yielding as large a quantity of fruits as may be possible, and in order to achieve this result, it will be necessary to resort to budding, grafting, or hybridization. Considerable success has already attended budding and grafting, but in these cases we are now realizing that another factor has to be considered, and that is the character of the stock on which the buds or grafts are placed, as some stocks, owing to their superior root development, are more suitable to certain soils than are others.

Some very valuable work in the direction of suitable stocks on which to graft or bud has been done at the East Malling Research Station. Here the work is mainly concerned with Apples, Pears, and Plums, but the general principles are applicable to work of this kind in all parts of the world. It has been found at East Malling that one variety of Apple, such as Worcester Pearmain, when grafted or budded on four or five different stocks, develops into a similar number of quite different shrubs or trees; different, that is to say, as regards their habit of growth, root and branch development, and yield of fruit. The careful selection of the right type of stock is, therefore, a problem of very great scientific and economic importance.

Another example of the diversity exhibited by plants of the same species is offered by *Eucalyptus dives* from Australia, which is the tree that yields piperitone, the essential oil from which menthol and thymol are obtained. It has been found recently that trees growing close together in New South Wales yielded four quite different types of oil on distillation, only one of which was piperitone. Botanically all the trees were alike; we are thus confronted with the fact that plants of the same species may vary considerably in their economic and physiological properties.

Very often in the case of herbaceous plants of apparently the same species, some may contain a poisonous property, while others may be quite harmless, and it is very interesting to

learn that in South Africa, where this state of affairs has been noticed, animals are able to distinguish between the poisonous and non-poisonous forms, and fortunately—unless they are very hard pressed—they will only eat the non-poisonous variety. It would be of considerable value if botanists were able to develop the same discriminative faculties as have been evolved by sheep and certain insects with regard to poisonous and non-poisonous forms of the same species.

With regard to mycology—that is, the study of fungi—there are many problems concerning the fungus diseases which attack economic plants, and one in particular, which threatens the Banana, may be mentioned by way of illustration. In the West Indies and in Central America the Gros Michel Banana is cultivated, and is the banana which is most generally offered for sale in our shops. The Gros Michel Banana is very badly attacked by the fungus *Fusarium*, known as the Panama Disease. This fungus blocks the water-carrying vessels in the plant and is a very serious disease, since the soil is infected and new banana plants planted in the infected soil succumb very quickly to the disease, and the fungus remains in the ground for many years. It is necessary, therefore, either to discover another variety of banana which is immune to the disease, or to make an attempt to select a strain of the "Gros Michel" which may be immune, or, again, to try to breed a new strain of banana which will be both immune to the disease and furnish a good edible type of fruit. Since bananas have to be carried long distances both on land and on sea, it is necessary that the bunches should be approximately cylindrical in outline, which implies that the individual bananas should be curved inwards and that no fruit should stand out from the stem, as any projecting points are liable to get bruised or broken in transit. Moreover, bunches of bananas with the individual bananas standing out at right-angles from the stem, as is the case in some varieties, take up a much larger space on board ship than do those which are incurved. It may happen in any breeding experiments with forms resistant to the disease that the offspring, though they may be immune to disease, may produce bunches of bananas which are not suitable for

transport, and should this be the case the new variety would be quite worthless. The plant-breeder, therefore, is faced with a very difficult problem, for not only has he to produce a form resistant to disease and with a good flavour, but also one which is suitable for the present conditions of transport on board ship. Work in this direction is now being carried out at the Imperial College of Tropical Agriculture, Trinidad, and some valuable results have already been obtained.

There is another problem of an economic character which also has to be investigated in this connection, and that is the proper cold-storage conditions which are suitable to different types of banana. At present a good deal is known about the proper conditions under which the "Gros Michel" variety will travel to this country, but it is probable that any new variety which may seem suitable for export, or any new form which may be produced by hybridization, will require somewhat different conditions from those which are suitable to the "Gros Michel." It will be easily understood, therefore, that the problems relating to the introduction of some new form of banana, or of almost any other tropical fruit, entail careful research along many different lines.

As I said at the beginning of my lecture, it is not possible to deal with all the modern problems covered by the science of Botany to-day. Much might be said about recent developments relating to the nucleus and the number of chromosomes which have been found in different varietal forms of the same species, but this is too large and complicated a subject to deal with in this lecture. What I hope I have been able to show you is that Botany is not a subject merely of academic interest, but is a really growing and live science, and—as we see it at Kew and other centres of like nature—is a science which brings us into close touch with all the activities of our daily life, and—so far as I am concerned, of course—with all parts of the Empire.

I hope, however, I have been able to give you a slight idea of some of the problems which confront systematic and economic botanists. Botany, I think you will realize, offers great fields of exploration to our young men, and opens out many vistas of useful and interesting work of the greatest benefit to mankind.

A LECTURE ON GEOLOGY

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IT is with considerable pleasure that I come down here this evening to say a word or two on the subject of Geology, in particular on the subject as it is known to-day. But I am also asked to predict, as the notice-board has told you, a little about the Geology of to-morrow. I am, however, more than a little dubious about the last-mentioned phase of the subject, the Geology of to-morrow, because one has to be very careful in venturing to make any prophecies in science, and, in this century, at any rate, one has to be more careful than ever, since many of the predictions that have been made in the past have had to be retracted. So you will probably notice that when I come to speak about *to-morrow* I shall be a little diffident.

The study of the earth is one which has occupied the attention of man probably since he appeared on it, and I desire to present this subject, when speaking to you to-night, rather from the historical and prehistorical points of view. To plunge straight into a talk on Geology and Human Life as we see them to-day would be, I think, rather unintelligible. I would trace the history, if possible, of some of the ramifications of the subject, some of the difficulties which have been encountered, and some of the difficulties which have been overcome in relation to the application of Geology to our modern life.

Geology to-day ministers, to a considerable extent, to our creature comforts, and it is in that relation that I wish to look at the science. There are certain demands which we make on life at the present moment; there is a certain standard of living among us, and it is in connection with that standard of living that I would emphasize some of the facts which Geology teaches us, for geological principles have helped materially in establishing and maintaining it. I believe, and it may be said to be

common knowledge, that if we are to have a high standard of civilization there are certain necessary adjuncts. For example, it is necessary that we have a certain amount of leisure; we must have at least a certain minimum of warmth, and we must have, in addition, a minimum, and an assured, food supply. In connection with all these factors Geology is playing a very important rôle, and has functioned considerably in the past. Now the possibility of a high degree of culture is largely a question of efficiency. If, for instance, we had to struggle hard for every bite of food we put into our mouths, and to fight for every bit of warmth we could obtain, then there would be no leisure, and certainly there would be no culture. This is precisely what seems to have happened in more ancient days, though we have no documentary evidence to prove it; yet we may take as circumstantial evidence the tools of stone which those ancient men used. They were at first clumsy and crude, and even the later types were inefficient, though indicating great skill on the part of the men who manufactured them. It was only after the discovery of metals that greater efficiency was obtained.

The discovery of metals was not entirely a chance affair, at least in this regard, that there are certain metals, notably gold and copper, which ancient man had, one might almost say, at his beck and call. At any rate he was able to obtain them direct from the earth. He found that certain natural materials were malleable, and therefore, so far as he was concerned, merely *malleable stones*, though what we now call *metals*; he was still in the Stone Age culture. And that can be quite fairly stated in regard to the North American Indian, even coming down to a late date. He was not a metallurgist.

We cannot state when metals were first used in a metallurgical sense, that is to say we have no actual record as to when men first began to smelt metals from their ores. But there must have been a period during which the only metals which could be obtained were such as occur in nature. There are, I am told, Indian tribes in the Hinterland of Chile to whom gold is the only metal, and they make all sorts of useful articles out of gold.

I have been led to understand on good authority that those Indians are prepared to trade gold fish-hooks for steel fish-hooks. Gold is the only metal they can procure, and it happens to be one which is particularly useless when it comes to manufacturing tools. It is too soft.

Copper has been found "native" in many parts of the world, and it can be used for a large number of articles. It can be treated by hammering until it becomes very hard. You can, if you feel disposed, try this experiment with copper wire: take it and twist, without bending, thirty or forty times, then you will find it has become brittle and will break across like a steel needle. It was only after the discovery of metallurgical methods of smelting copper and tin from their ores that it was found possible to get another hard metal, a mixture of these, namely bronze. And so we had the Bronze Age. As I have hinted, the actual use of metals far antedated the Bronze Age; there is evidence that gold and copper were used before that time. But the users were not producing metals as such. In their hands copper might be considered a malleable stone. In Europe, the Bronze Age followed the Stone Age, with the Copper Age somewhere in between: but we are unable to fix the precise dates of any of these stages of culture for they probably overlapped.

The production of bronze, however, was a marked advance, since bronze is not a natural metal. We find metallic tin occasionally, in nature, as a mineralogical curiosity, but it does not occur in bulk. The idea of mixing metals together, so as to get a hard alloy, and one, moreover, which was capable of being run into closed moulds—because the addition of tin to copper facilitates that possibility—was a very big advance. Where this notion arose I do not know; probably it originated at more than one place, but it must have taken a good many years to develop generally. Yet the number of possible localities is limited, because ores of tin are not widespread. This is reflected in the case of Africa, where, apart from Egypt, there appears to have been no Bronze Age; there was a Copper Age, then an Iron Age. But, in Egypt, copper, bronze, and iron were all known at about the same time; and probably at about

the Fourth Millennium B.C. workers in these metals were skilled metallurgists. It is interesting to note that Agricola, writing in his *De Re Metallica*, the oldest treatise on metallurgy, claims Cleopatra as a metallurgist. We therefore know that the ancient Egyptians were skilled metallurgists.

As metals were frequently only obtainable in places far removed from centres of culture and industry, the users often had curious ideas as to how they were actually produced. Many of the classical traditions were probably based on stories imported, with the metals, from other countries. For example, we have the tradition of the Cyclops, the one-eyed monsters. The Cyclops, or the men who were called Cyclops, were, no doubt, nothing but hard-working miners; they lived in caves or caverns, and it seems quite clear that they wore their lamps for convenience hung on their heads, just like the modern workers in that industry. Their arduous work developed a brawny physique, and to the casual traveller they seemed like monsters with a single, piercing, flashing eye in the middle of their foreheads. Again Herodotus says in his *History* that gold was collected on an island, Cyraunis, off the coast of Africa by beautiful women who employed feathers dipped in pitch. Herodotus says he is not sure if this is true; but doubtless they were women who were washing gravels for gold and picking out the particles by using quills, greased perhaps at the end to facilitate the operation. Later writers, like Pliny, knew even less about the modes of winning metals. There is a reference to obtaining gold from ant-hills, and, impressed no doubt by the quantity of gold actually won, they stated that these ants were as large as foxes.

Other legends indirectly tell of the search for metals. Jason, who went in quest of the golden fleece, was really searching for metal, as Strabo has pointed out. The story goes that Jason set out to secure the golden fleece said to be in Colchis. This he did at the instigation of his uncle. The fleece or fleeces were doubtless skins over which gold-bearing sand and gravel had been washed, the little particles of gold sinking among the staple of the fleece and so being caught. This method is used to-day, though pack-sheet, or other coarse fabric, replaces the

fleece. Probably Jason was not such an altruistic individual as we are apt to consider. The alleged golden fleece was the excuse to justify his piratical adventure and the "thief's bargains" he had made in his expedition which secured so much gold and other merchandise. And thus the first known voyage of any magnitude was in reality a trade voyage. This legend, then, merely commemorates voyages in search of metals; and Jason merely typified the ancient merchant adventurer. At a later date, the fifth century B.C., the Phoenicians were sailing through the Pillars of Hercules (Strait of Gibraltar) in search of these same substances.

When we consider the enormous advantage of metal tools, such expeditions are not to be wondered at; in fact no discovery, until the exploitation of coal, has made such a change in human life as the discovery of metals. And our modern Argonauts still continue the search for them, though their efforts are directed towards base as well as precious types.

How have these discoveries secured more leisure and comfort for man? Metal tools certainly lead to greater efficiency in work, and therefore will secure more leisure for the user. But that is merely the beginning of the story. Better agricultural instruments ensure greater food production and so a larger and larger population can be supplied with the necessities of life. Metal tools render a greater division of labour possible, and permit the development of industries other than hunting and agriculture—the only natural industries. Agricultural communities become town communities. Trade developments demand stability of market-places, and fixed buildings soon lead to architectural efforts of great magnitude and pretension. Further, a certain amount of supervision of labour becomes necessary, and thus we see arising a class of men who use their brains rather than their fingers. They supervise and direct the labours of others. Society, under such conditions, must of necessity become more and more specialized, and, as a matter of fact, has reached to-day a complexity never attained before in the history of the world.

It is, of course, hardly fair to credit the discovery and exploita-

tion of metals with all this development, but there are few things which are so essential to modern life as metals. Without metals, the use of the electric current, of gas, and of water for commercial and domestic purposes would be impossible. These materials are only taken as examples, for there are a hundred-and-one ways in which metals render our homes habitable or luxurious.

Our newspapers, books, music, and most of the facilities we consider necessary for the higher culture would be equally impossible, for the multitude, without metals. A few, it is true, in an age when metals were scarce attained a very high degree of culture. The Egyptian, the Greek, the Persian, and the Roman Empires, left no mean legacy of culture to the world, and even in earlier generations certain races had developed a high standard of living.

In later days, and, as far as we know at present, uninfluenced by any of these older civilizations, the Inca and Aztec cultures may be instanced. But each and all of these episodes showed culture as the prerogative of the upper classes; the masses still had to toil incessantly, and therefore with but little chance of enjoying leisure. To-day, on the contrary, our masses have a culture and a degree of leisure quite unknown even to the most affluent citizens of Greece, Carthage, or Rome.

Try to imagine what would happen if the supply of metals were to give out. Could we revert to the use of wood and stone without loss of our culture? We could not!

And there is another side to the matter, for nearly every metal has a very pleasing appearance, and metals can be made more pleasing by working them into objects of art and of craftsmanship. They are, on the whole, durable, and much of the skill and of the ideals of the past has been handed down to us in articles wrought in gold, silver, bronze, and copper. Here is something which stimulates thought and stirs up latent talent; something that urges the craftsman of to-day to emulate the highest ideals of the artist of earlier times, and even to better his results. To some of us, alas, such skill has not been given; we cannot do more than wonder at the industry and ability of those earlier craftsmen. Yet who amongst us can

go through our British Museum and fail to be proud of the aspirations and attainments of the human race? Who can help saying, with Tennyson:

> Yet, I doubt not, through the ages one increasing purpose runs
> And the thoughts of men are widened with the process of the suns.

But leisure alone does not build up a civilization. If the use of metals merely provided leisure to sit and shiver in an inclement country, it would have been better if they had not been discovered; and, if we still had to have recourse to what Kipling has called the "grisly diversion" of taking exercise in order to keep warm, small culture could develop. Lofty thoughts on an empty stomach and in a chill atmosphere would be strangely difficult to realize.

Therefore a second necessity for cultural development is adequate warmth. Man seems to have been able, in all ages, to kindle a fire; whether that was as a protection against wild animals, or for his comfort, we do not know. Up to a comparatively late date the fuel for these fires was mainly wood, and to this day in many parts of Europe and other continents wood is practically the only available fuel. Even trains and steamboats are worked on this fuel, though, as a result of its low efficiency, their range is comparatively restricted. We can say with truth that the wide penetration of our modern European civilization is due largely to an efficient means of producing heat, whether for giving comfort or for producing power. Now "comfort" has many aspects, but among the chief are warmth and illumination.

What are the three most important means of modern heating and lighting? They are undoubtedly the use of coal, the use of oil and gas, and the use of electricity. In early days, wood fuel was that most commonly used. But it produces a very smoky fire, and must have rendered the cave-dwellings or tents or even houses almost uninhabitable. The manufacture of smokeless fuel, such as charcoal, would make things more bearable, and there is abundant evidence that this was achieved prior to the beginnings of our present civilization.

It may be objected that, so far as mental culture was con-

cerned, man had attained to the highest without other means of warmth and light than that afforded by the natural fuel supplied by vegetation or by animal fat. That is tenable historically if we consider only the *few*, but in the case of the *many* the answer is emphatically, No! The advent of concentrated fuel has opened up a new world to the masses, and made possible a civilization not known before. Whereas in the past the few certainly had very many comforts, to-day the populace has easy access to most of them. Civilization, moreover, has spread into countries to the north of those where the climate was best suited to man as a mere animal. From Southern Europe the spread to the north is very marked, and the population in the North Temperate Zone to-day is greater than at any other time in the world's history so far as it can be read.

The history of the use of coal is most interesting. We are told that the Chinese knew and used it many centuries before the Christian Era, but the Chinese never *exploited* coal to any extent. Theophrastus tells us that smiths used stones in their furnaces, and there is no doubt that the stones were coal, but again there was no industrial exploitation. In Britain, in 853 A.D., we find coal first mentioned, but until the twelfth century no real use was made of it. In 1130 the Bishop of Durham mentions black stones which people burned; but it was not until 1180 that coal was first exploited industrially, when the Midlothian coalfield was opened. The Newcastle coalfield commenced working in 1239, and soon became the most important coal producer in the country.

Why did development not take place until such a late date? The answer is painfully obvious. A smoky coal fire is more irritating to the senses than a wood fire, and it is little wonder that in 1306 Londoners protested to the King against what was called "sea-coal," a name still perpetuated in Seacoal Lane, a little street near Ludgate Circus. In fact it was the serious depletion of the forests to supply heat for industry that compelled people to use coal. Metals were still scarce in those days, though they were exploited where possible, and in 1570 Queen Elizabeth was petitioned to close down the ironworks at Furness because of the destruction of timber in the neighbourhood. The

Newbattle coalfield, which was opened in 1180, commenced for a similar reason, namely the depletion of the forests. The most important local industry was the production of salt, and it was obtained by evaporating sea-water. The scarcity of timber in the neighbourhood forced people to turn to alternative fuel, and coal, which was known to occur locally on the seashore, was the answer to the demand. Coal, then, is a modern commodity because it is an unpleasant fuel for an open hearth with no chimney.

The replacement of charcoal by coal was a slow process, and in 1769 we find the Parisians protesting against the introduction of coal. Yet consider what Britain, Germany, America, France would be to-day without coal. Through these countries and the production of coal the bulk of the populace of the world has been raised from a position of almost hopeless slavery to a condition in which the Brotherhood of Man is within reach. There are some who bemoan this state of affairs and talk of "the good old days"; there are always people who talk like that. But why was there not a sudden great development when once this new fuel was exploited? The answer is that wood fuel was still plentiful and was easily obtained, whereas coal had to be transported. Transportation of coal over the roads of that date was almost impossible, and its transport by sea was slow. Also the fumes from coal were unpleasant, and the hardship of winning coal from the earth was great. Only the lowest class of labour would consent to work in the mines, and these miners were of such bad behaviour that laws were passed prohibiting them entering towns during certain festivals; for example, Midlothian salters and miners were prohibited from entering Edinburgh on certain Holy Days. Hugh Miller, who was working as a mason in Midlothian in the middle of last century, said the miners' women had all the traits of a slave race. As a fact the miners *were* slaves, because they could not transfer their labour at will from one pit to another; they had to obtain a certificate from the old master before they could work for another. This state of affairs continued until 1799; so we had slaves in this country less than 150 years ago.

The output of coal was comparatively small at that time,

so we must conclude that coal had come before its time, or, putting the position otherwise, there was little reason for exploiting this commodity.

Of course, *some* industrial use had been made of coal in the Middle Ages. In the reign of Edward VI one English writer speaks of it as "That thinge that France can live no more without than the fyshe without water, that is to say Newe-Castele coles, without which that they can nother make stele worke nor gonnes, nor no manner of thinge that passeth the fier." That was somewhere about 1550. But we can say that a hundred years ago coal was only beginning to attract general attention, and it is almost incredible that the history of coal production should have been a negation of the principle we have been following, namely, that more efficient methods of heating would lead to a higher standard of civilization.

But what has happened since then? The invention and improvement of the steam engine has altered all modern life. Coal has become an essential fuel; the countries which produce it have become prosperous, and the lot of the people, including that of the miners, has become much better. Britain now carries four times the population it did a hundred years ago, and that is due to the exploitation of this substance. From being a slave, many people think the miner has now become a tyrant; at any rate he has access to all the benefits which a high civilization can bestow, and is not always as sympathetic to the wants of others as he might be. The coal industry is subject to periods of trade depression, and recently alternative sources of fuel have been developed, as we shall see. But, for the miner, as as well as for the rest of the community, the exploitation of coal means a higher standard of life, and the chance of a greater and more refined civilization. This exploitation was not essentially geological; but without geological knowledge the coalfields of the world would never have been discovered or opened out as they have been.

Why is this? Coal is a stone, it is a rock. It happens to be inflammable, but that has nothing to do with the fact that it is rock. And it is a sedimentary rock, deposited in sheets and layers; and, in some cases, the sheets have become twisted

and contorted, in others they have been broken across, and so troubled by earth movements that it is very difficult to follow the sheet of material underground. Miners will suddenly come to a place where the coal disappears. The question is whether they must drive up, or drive down, so as to strike the coal beyond the place it has disappeared. In such cases the geologist is at once called in, and it is in these difficulties that he can, and does, help in the *exploitation* of the coalfields.

Again, the geologist in his work has shown where it was possible to find coal when its presence is not indicated at the surface. No better example of this can be found than the nearest coalfield to London, namely, the East Kent coalfield; the establishment and working of that coalfield is the direct result of a geological prediction. It is true that that prediction was based on the assumption that certain geological structures continued underground from the West of England and South Wales to Kent, and that they ran thence into the North of France. Godwin Austen predicted that there should be found a coalfield in the North of Kent. It is true that his prediction did not work out absolutely as he had stated, because we know he could not see through the thickness of the stones farther than anybody else could. But his geological knowledge convinced him that the presence of such a field was a reasonable expectation from the known facts, and, when boring was carried out, the expectation was in great measure realized. Speculation as to the formation of these coal seams—which I am afraid I have not time to go into now—is another way in which geological theory has helped, and will help, in the future exploitation of other coalfields. We know the conditions under which coal was formed, and we can discover signs in the rocks indicating where such conditions had supervened and where coal might possibly occur.

To get some idea of the amount of coal which is now raised annually, it might be as well to consider a few figures. In 1840 in Britain about thirty million tons of coal were produced. In 1855 in Britain, about sixty-five million tons of coal were raised; and in America eight or nine million tons. In 1928 the world's production was 1,440 million tons of coal, Britain producing

about 245 million tons and U.S.A. some 500 million tons. That gives you some idea of the enormous change which has taken place, not in a century, but in little more than half a century. It shows the tremendous amount of material which has been obtained, to a great extent, as a result of geological work. In our own country the geologist has always been consulted in difficulties in regard to coal-mining, and, naturally, he has produced maps of different areas; so that no person would think of sinking a shaft until a survey of the area had been made; moreover, trial borings always precede the actual opening up of a field. But, even after a coalfield has been opened up, geological experts have to be consulted when difficulties arise, for example when seams are broken across as a result of earth movements, e.g. geological "faults."

While the production of coal has reached an enormous quantity, there are alternative fuels; and if geological work was necessary in the opening up and exploitation of coalfields, it is far more essential in the location of oilfields, which yield our second fuel type. It is oilfield exploitation which has provided a use for the trained geologist in the past decade. Geologists have scoured the wastes and jungles of the world in a search for petroleum, and, in modern times, no commodity has so much hastened the development of territories which, up to that time, have been only thinly populated and uncivilized. The output of oil in 1928—the year for which the last figures are available—was 180,000,000 tons, which is equal to one-eighth of the production of coal, an extraordinarily large figure.

The advent of this new fuel has had many repercussions. It has resulted in the production of new types of engine, it has opened up avenues for producing power which were not known before, and it has added enormously to the enjoyment of life for the worker, to that extent increasing his efficiency, and, by opening his mind to other fields of thought and observation, has increased his culture. No recent discovery, except, perhaps, that of wireless sound transmission, has had such an effect on civilization as the discovery and use of oil. We have only to cast our minds back to the days when travel

in London, and to and from the outskirts of London, was by horse traffic, and to compare with conditions to-day, to realize that. Take, for instance, a journey to Kew; in those days it was quite an outing, and people only arranged to take such a trip once or twice a year. Similarly, travelling to town used to be a very wearisome business, and took a considerable time. Now, with motor-buses, electrical vehicles, and trams or cars, the travelling time has been cut down to such an extent that one can now easily do a journey to Brighton and back in a day, when formerly it was only a journey to be undertaken once a year for a holiday. It is the advent of the new fuels which, as much as anything, has rendered this possible. Oil was known to the ancients, and was used by them; coal, as far as we can gather, was not. But the oil which was used by the ancients was employed for medicinal purposes, or, when it was dried out, for plaster or cement in buildings. The derivation and location of words is always interesting. Some words of common use in the oil industry are both ancient and local in origin. The derivation of the word "bitumen," though somewhat doubtful, is believed to be Hebrew, and was clearly associated with Asia Minor, where this material was first referred to in history. Bitumen was used to cement the stones of buildings, and the type found at Is or Hit was referred to by classical authors, and was employed for this purpose at Babylon and other places. "Asphalt" is a Greek word, introduced by the Phoenician traders. Pliny uses the word "maltha" for a thick, partially inspissated oil, which was employed for caulking the seams of ships, and naphtha was used for flowing oil. They are all very old words and were used around the area of the present Baku and Baghdad oilfields. The uses of these substances were few—the more fluid were used in medicine as salves, the more solid as a cement in buildings or to caulk the seams of ships, but there was no commercial exploitation. In 1847 James Young, at the instigation of Lord Playfair, commenced working flowing oil at Alfreton in Derbyshire. Experiments had been made a hundred years before that to obtain oil by distilling coal; but they were not successful. Young thought the Alfreton oil was produced by alteration of coal underground; and when

the supply at Alfreton was diminishing he examined all the coals in the country with the view to discovering one that would yield a deal of oil on distillation. He found that the Bog-head coal of Torbane Hill, Linlithgowshire, yielded 120 gallons of oil per ton. In 1850 he took out Patents for low-temperature distillation of coal, and started working this material. But the mineral soon became exhausted. Meanwhile he had located several rocks of a shale type which would yield oil if distilled in closed retorts, and thus discovered the oil shales of the Lothians. They had not been considered very important by geologists, as indicated by the fact that old geological maps did not show the oil shales; but, as soon as Young's discovery became known, the geological survey officers issued a new set of maps showing where these shales occurred. The shales were exploited by different companies until two years ago, when the mines were shut down and commercial exploitation ceased, for the competition with "flowing oil" in other parts of the world had become too severe. Few commercial explorations have occupied the attention of geologists so much in the past few years as the oils of the Pennsylvania type, that is, flowing oils. Here there is no question of distilling shales; the oil is present as such in the rocks. The principal rocks are sandstones and limestones, and often the oil is present in very large quantities.

The problems associated with the exploitation of oil are geological. For instance, we find that the oil wells, to be brought into a condition for yielding, have to be very carefully selected; that is to say, the *sites* have to be carefully selected; and, until the geologist has examined the country and has worked out the geological structure, it is often very difficult, in fact almost impossible, to put in the first oil well. It may easily happen that if the well is put in wrong the whole exploitation of the field may be greatly delayed.

Suitable conditions for oil pools can be more or less determined by the geologist; and it is little wonder that he has been responsible for the preliminary exploitation in connection with oilfields.

There is another fuel to which one must refer, and that is

electric power. It may be produced by the exploitation of what is known as "white coal," i.e. water power. It looks as though this electric fuel will be the fuel of the future. The great advantages, in its cleanliness and its handiness, cannot be emphasized too much. It can be shut off and turned on with no very great amount of trouble. So long as coal and oil are necessary in order to produce this type of energy, the problem, as far as the geologist is concerned, is merely a problem of coal or oil; but where electric power is produced from water power the geologist seems not to come into the picture. If electricity is the fuel of the future, it looks as though the work of the geologist in exploring the sources of fuel is finished. This state of affairs applies to such undertakings as we find around Niagara Falls. Nature has been very kind to man there; she has supplied a huge reservoir of water in the Great Lakes, and a convenient fall over the limestone of the Niagara Gorge. But Nature has not always been so indulgent, and where man tries to produce an artificial waterfall the advice of the geologist is again necessary. In electric power, or any other source of energy, a continuous supply is essential. In the case of coal and oil the producer and user of the energy constitute one and the same unit, and this unit is easily detachable, the electric unit is not. Suppose a steam engine or a motor-bus becomes damaged, the whole railway or motor-bus system is not immobilized; but if a generator at Lots Road or any other power station breaks down the whole Underground system may be held up. One may say a generator is equivalent to the whole coal or oil supply, but even if this be only partly true, for there may be several generators, we can say that continuity in coal and oil supplies is much more easily obtained, and storage of material to tide over a possible discontinuance can be arranged. Some electric power can be stored in batteries, it is true, but the margin between continuity and breakdown is rather small. It is easy to mitigate this difficulty if we generate electric power from water power, as is being largely considered at present. Such hydro-electric schemes depend on a large storage of water, and sufficient storage has rarely been accomplished by nature. In most cases man has to supplement nature by

erecting dams to store up the water and thus secure that the energy may be produced in bulk and a continuous supply rendered possible. The selection of the site for a masonry dam is very important. In the last twenty-five years we have seen the bursting of dams, or rather the overturning of dams, because the site selected has not been appropriate. There has been leakage underneath the masonry, thus softening the foundations, and with the pressure of the water behind the whole dam is overturned, and down the valley rushes a sudden flood, which often leads to great loss of life. There is, however, a way in which the geologist can help, namely by indicating a good selection of the site for the dam.

Such hydro-electric works are still in their infancy, because there are distinct limits to the distance we can carry electric power. But although they are in their infancy, gradually more and more of these schemes are being put into force. As regards fuel, as regards the exploitation of materials to add to the creature comforts of man, the geologist is at the present moment filling a very important place and doing an important piece of work. And whether we deal with coal, or oil, or with hydro-electric power, the same statement can be made, that somewhere or other the geologist has to come in if the work is going to be done well.

I must not strain my invitation here by going on too long, but there are one or two points I would like to make before turning to the other side of the picture, the future.

I have spoken about the production of warmth and light, but there is something more than that. In our modern civilization great buildings have become essential, and here again the geologist is important. He is able to pick out the stones which are essential for certain works. The geological engineer works out breaking strains for certain stones, and can say: This stone may be used here and it would be dangerous to use another. Therefore the selection of these materials is frequently a geological problem. In the building of the Piccadilly Museum every stone was selected by Sir Henry de la Beche, who was head of the Geological Survey at the time, and these stones have stood the test of time. But other buildings, in which some

of the stones used were those he had rejected, have not stood the test of time. Then there are artificial stones—bricks—made from clays. Here again the geologist gives very important information with regard to the possible uses of the materials. Some clays can be used for making ordinary bricks, others for making bricks which will stand high temperatures. In the clay industry, as a fact, geological information is being greatly used at the present moment.

Apart from the stones, there are the materials for cementing stones together; and here the person who is versed in Geology is able to give advice with regard to the exploitation of certain limestones: those which are suitable for making plaster, and others for making cement. And in many ways the geologist can advise persons who are manufacturing these various materials.

I might refer also, for a minute or two, to another most vital material in large communities, and that is the supply of water. The populace hardly realize what has to be accomplished in order to permit them to have a tap and run water out of it. I have heard people bemoaning the water-rate. There is no real cause for them to do so. They are at liberty to take a bucket, go to the Thames, and get as much water as they like. But carrying a bucket of water from the Thames to, say, Herne Hill, does not appeal to many; they would rather pay the water-rate. In this connection, also, the geologist may be regarded as a very important individual. It would be easy, of course, to spend a deal of time discussing the question of water supply, but that, I am afraid, would take up much more time than there is at my disposal.

The water supply of London is one of the most interesting in the world, because it is so varied. Some of the water for the use of London people comes from the Thames, some of it comes from the New River. There natural springs were harnessed in 1613, and the water, from that date to the present, has been continually flowing down that New River to the basin at Clerkenwell. A further moiety of the supply comes from wells sunk below London, because the geological structure and rock type there happens to be suitable. But the determination of that structure is a geological problem, and the geologist is

constantly being brought into consultation when questions concerning the water supply from underground are discussed. Hydro-electric power schemes have been mentioned, but there are also great reservoirs constructed for water supplies. The present supply for London was considered adequate until the year 1935, but we know what happens in London in a hot summer—a scarcity of water is threatened. A scheme has been put forward for the augmentation of London's water supply, namely, by constructing large dams in the Welsh hills, and bringing a supply of water from Wales to London. That shows what importance is attached to the question of the water supply. Any such schemes will involve advice from geologists as to the positions in which these dams should be established.

But if the supply of water is important, the disposal of water after it is used, i.e. the disposal of sewage, is equally important. It is a part which is sometimes forgotten by the public. We are using in London 270,000,000 gallons a day, equal to a good-sized river, and it is necessary to get rid of the water which has been used. In schemes for sewage disposal the geologist is a most important person, because he can advise on the selection of the site of the sewage farm or disposal scheme; some of these depend on the soil being non-permeable, and the geologist is the person who can say whether the soil is permeable or not. It is true that he is not so frequently called into consultation in these cases, but he *is* called in.

Thus in many ways, in the production of metals, in the production of fuels, in the production of building materials, the exploitation of the water supply, the disposal of effete water, the geologist has established the right to be called upon for advice.

But if he has something to say on these material aspects, he has also something to say on the philosophical side. As a result of research work in mineralogy and palaeontology, or in discussing the structure of the globe from the standpoint of astrophysics, geological workers have greatly modified philosophical ideas. The exponents of Geology in our universities and academies have taken a firm stand for accuracy in observation and common sense in deduction. Many have suffered for

the attitude they have taken, but the present freedom of thought that the philosopher enjoys was won for him very largely by the struggles of geologists like Lyell, Darwin, and Huxley. Misrepresented and even ridiculed in print, frequently ostracized in society, they ultimately showed they were not wreckers of what many regarded as sacred, but searchers after the most desirable thing in the world—truth.

So much for the past and the present. Now what about the future? In the future some exploitation of the substances already considered must be continued. In this exploitation the work of the geologist will still be of importance. But at the present moment there is developing a new kind of geological work.

I refer to the exploration for materials by geophysical methods. Tons of gelignite are exploded daily in the exploration of oilfields by sound-ranging apparatus, while certain other physical methods are being used to supplement the work of the geologist. Up to the present these methods have worked well where the geologist has already explored the region. New ground also has been opened out as a result of these surveys, but there is still some doubt about the efficiency of the methods in all cases.

One of the important instruments of this type is a very delicate balance, known as the Eötvös balance. It is a machine which measures the rate of change in gravitational force, and of course the force is that between the plummet or "bob" of the machine and the earth assumed concentrated at its centre. If there is heavy material present between the "bob" and the centre of the earth, the effect is great; if light material the effect will, of course, not be so great. This instrument is so delicate that, after balancing, there is an appreciable deflection when quite light material is interposed in the vicinity, while heavy material causes a much greater deflection. By means of such a balance the whole area can be explored, and lines of uniform differences in gravitational force can be plotted on a map. The differences are due to the presence of material underground heavier or lighter than the normal. These machines have been used in exploring for metallic substances which were

not shown on the surface of the earth, and are also employed in detecting and delimiting oilfields. Several oil companies are using this balance in various fields; and it looks as if that instrument will be employed in the future to a much greater extent that it is at present. It certainly savours of necromancy but is really a machine designed to make use of a sound scientific law.

Another method that has been employed is that of exploding charges of dynamite underground, and then listening to the sound reflections from rocks in the vicinity. In that way some of the oilfields in Persia have been exploited and the work is proceeding at the present moment.

Again there are electrical methods, by which the presence of a metallic substance can be detected underground because of the change in electrical potential which occurs alongside metallic ores. All these plans make use of sound principles of Physics.

The geologist, therefore, is being replaced to some extent by the physicist. How far it will continue is a bit uncertain, because where the geological structure has already been ascertained the best results are obtained. Yet these methods are methods for the future. They have been used for the exploitation of oil and water, as well as for metallic substances. How far they may be successful and whether they can be used for other materials we do not at present know, but there is that possibility for the future. Indeed a company has recently been floated to perform such geophysical work for mining concerns.

The microscope, which has been applied to the study of rocks, has given us an insight into their structure that was impossible to ascertain fifty years ago; and we cannot say how much further that study will take us in the next fifty years.

But there have been more delicate instruments invented than the microscope. There is, for instance, the use of X-rays for examining minerals. First started by Laue in Austria, the idea has been improved by Sir William Bragg and Professor Bragg in this country. New methods have been devised by these workers and their colleagues until the X-ray analysis of materials has become a method of testing and determining the

constituents of natural and manufactured products of many kinds. Indeed X-ray analysis of minerals has almost transferred the study of minerals from the geologist to the physicist. Yet, in essence, the X-ray machine is merely a more delicate engine than the microscope. At the root of the whole matter is the wave theory of energy. The light waves we use in microscopical work constitute what is called the *visible* spectrum; X-rays constitute one part of the *invisible* spectrum. Other invisible rays being used at the present time are ultra-violet rays and infra-red rays. These are all used by the biologist, the mineralogist, the chemist, and the physicist, but they only represent parts of the complete spectrum. There is no reason why minerals and rocks should not be examined in all these ways. There is no reason why instruments for infra-red rays, ultra-violet rays, X-rays, and other kinds at present unused should not be part of the geological outfit, just as the microscope is to-day. That something of the kind is possible seems to be indicated by recent experiments. The minerals contained in certain rocks have been detected by passing thin sections of these rocks across a little aperture through which X-rays are coming. It may be that future developments will allow the geologist to dispense with the microscope in rock examination and substitute the X-ray spectroscope.

Nor are future discoveries likely to be limited to the realm of inorganic nature. Workers in palaeontological geology are discovering new fossil types. They are filling in gaps in our records of the past, and some day we may be able to clear up notions of organic evolution at present rather obscure. We know definitely that we shall have a more complete record than we possess to-day, and that that extra knowledge may clarify present ideas concerning the conditions of life in the world in past times. We may, for example, be able to say something more definite about climates in former days than is at present possible. The knowledge of the geologist in respect of conditions in earlier days is very different from what it was even twenty years ago. Many beliefs then held, very definitely, have been shown to be wrong by subsequent discoveries made in palaeontology: and there are still large fields for the palaeon-

tologist to explore in the future. Nor will future geological research be confined to a mere recording of observations. The philosophy of the subject cannot fail to be influenced by future discoveries, and it is likely that ideas of the past history of the earth will become more and more accurate as the studies of the sciences progress.